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UHF-TV Klystron Multistage Depressed Collector Development Program

Final Report

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Summary

Development efforts at NASA to achieve highly efficient microwave transmitters for space applications resulted in achieving multistage depressed collector (MDC) technology with great potential for efficiency enhancement. The UHF television community recognized the potential of this technology for reducing operating costs; preliminary analysis indicated that applying MDC technology to the power klystron used in UHF-TV transmitters could reduce amplifier power consumption by half. Consequently, this development program was organized as a cooperative effort between NASA and the UHF-TV industrial community.

The development program proceeded and achieved an MDC design by using computer-aided design techniques. Computer modeling codes were developed to allow performance simulation, and by an iterative process an optimized design was achieved. A four-stage design was selected which would operate with equal voltage steps per stage.

Optimized MDC operation requires collector electrodes with low secondary electron emission. Coating materials were investigated for this application and the NASA expertise was utilized. A carbon coating technique was developed using a sputtering application method. Equipment was acquired to allow coating the large collector electrodes for the TV klystrons.

An experimental model 60 kW UHF-TV klystron was constructed and evaluated. Test performance shows close agreement with the computer predictions. Power recovery varied from 74 percent with no rf output to 57 percent at saturation output. The overall efficiency was 71 percent at this point, compared with 55 percent without the MDC. For television operation, the input power is reduced from 118 to 51.8 kW by use of the MDC, consequently, reducing the power to less than one-half.

The MDC design has subsequently been applied to another UHF-TV klystron, a four-cavity 60 kW klystron of external cavity design. Two tubes of this design have been constructed and evaluated with similar performance. One tube has amplified simulated television signals and has demonstrated good performance.

UHF-TV KLYSTRON MULTISTAGE DEPRESSED COLLECTOR PROGRAM FINAL REPORT

1.0 INTRODUCTION

A program to incorporate depressed collector technology into UHF-TV power amplifier klystrons was initiated in June 1984. Support for this program, in addition to NASA, was provided by a cooperative group which included the National Association of Broadcasters, the Public Broadcast System, transmitter manufacturers and Varian. This report describes the accomplishments of this development program.

UHF television stations are particularly concerned about minimizing operating costs. The cost of electric power is a significant segment of the overall costs and results mainly from the power consumption of the final power amplifier klystron. Maximizing klystron efficiency has been a continuing effort but the current designs represent close to an optimum. The characteristics of the amplitude modulated television signal result in klystron operation at power levels below the optimum efficiency condition. Thus, the true operating efficiency is typically about 20 percent, even through the klystron can provide over 50 percent efficiency at saturated output. Multistage depressed collector (MDC) technology can overcome this problem; by recovering energy from the spent electron beam, the efficiency can be maintained at a high level even for reduced power levels.[ref. 1,2,3,4]

An MDC design was achieved based on the approach described by Kosmahl[ref. 4]. Computer aided design technology was employed to obtain an optimum design. Also developed were surface coating treatments for the MDC electrodes to minimize the adverse effects of secondary electrons. An experimental 60 kW klystron incorporating this design was constructed and evaluated. Test data indicate that the program objective of reducing power consumption to less than half has been accomplished.

2.0 KLYSTRON DESIGN

Seven tasks were identified to be accomplished during the program, which are listed in Table 1. These tasks were addressed according to the program schedule shown in Figure 1.

The Varian VKP-7555 klystron was selected as the basis for the new multistage depressed collector klystron. This tube provides 60 kW operation at the high channel TV band from 700 to 850 MHz. It utilizes a five-cavity interaction circuit tuned in a manner to optimize efficiency while providing a 1 percent bandwidth suitable for linear operation in TV service.

Table 1
Tasks to be Accomplished During the
Depressed Collector Development Program

Task	Description
1. Computer Simulation	This task is to develop a mathematical model to describe the klystron to determine electron velocity vector distribution at the collector entrance.
2. Computer-Aided Design	The electron beam defined above is injected into the collector region while the electrode shapes are adjusted to maximize recovered energy but yet minimize returned electrons.
3. Material Evaluation	Collector electrodes need to have low secondary electron yield since secondary electrons degrade power recovery and can also cause regeneration problems (sync pulse ringing).
4. Collector Assembly	At least ten collectors are to be evaluated.
5. Test Equipment Design and Construction	Provided by Varian to allow test and evaluation of the ten collectors of Task 4.
6. UHF-TV Klystron	Provided by Varian to allow test and evaluation of Assembly the ten collectors of Task 4.
7. Performance Demonstration	

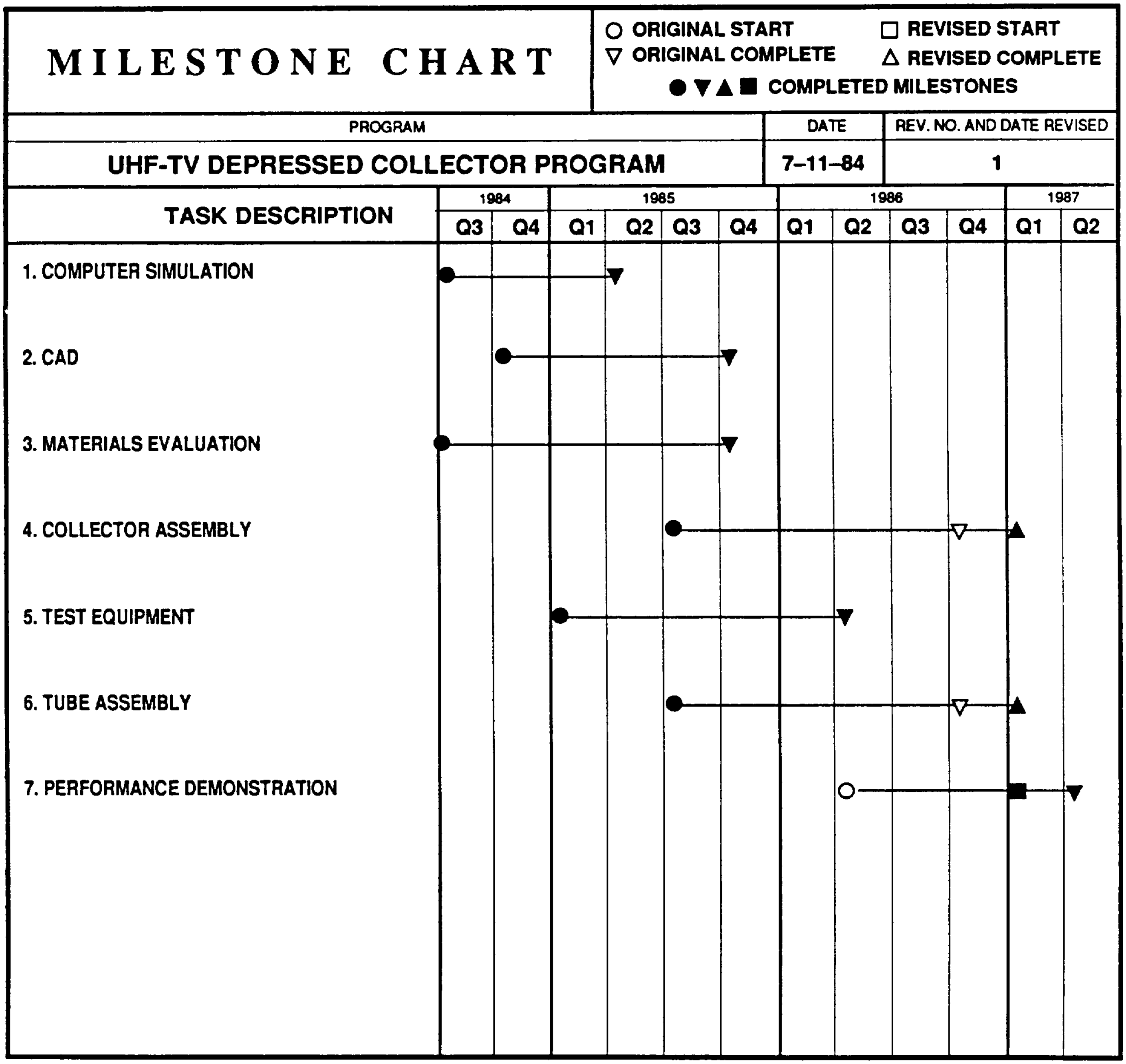

FIGURE 1. PROGRAM SCHEDULE

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Detailed technical data for this klystron are included in Appendix A.

The first step in the design process was to develop a mathematical model to describe the performance of the VKP-7555 klystron. A recently developed large-signal program, called the 2dRF Program, was used for this purpose. This is a self-consistent particle and cell code which uses two space and three velocity coordinates in a time stepping process. Measured beam and circuit parameters were used for input conditions and tube performance was calculated using five rings of charge in radial direction with ninety discs (450 rings) per rf period. The calculated performance compared very well with actual measured data. Close agreement was achieved for gain and efficiency across the bandpass for two tuning patterns. In addition, the computer provided data on electron velocity at the output of the interaction circuit. These data for various power levels are shown in Figure 2. This velocity information and the space coordinates were then used for the input conditions for the collector design.

The collector design was accomplished by using the Varian HGUN Program. This program traces charged particles through electrostatic and magnetostatic fields and allows determination of electron trajectories (including space-charge effects) for selected electrode geometries. Included in the program are diagnostics appropriate for depressed collector analysis and include current collected by each stage, power recovered by each stage, and thermal power dissipated on each stage.

The HGUN beam input conditions were determined by matching the field boundary conditions at a plane between the interaction circuit and the collector entrance. A trajectory was calculated for every fourth particle of the 2dRF program, resulting in 112 trajectories.

The initial collector geometry was selected to provide a decelerating electric field with moderate outward radial acceleration. Care was taken to assure no regions of convergence existed. In addition, the geometry was selected to be simple in configuration and within the dimensions of the existing undepressed collector. Repeated design refinements (iterations) resulted in an optimized electrode geometry. More than ten interim designs were evaluated during this process which led to the selection of the final design.

Figure 3 shows the equipotential lines for the final collector geometry. Equipotentials are plotted for the electrode potentials and plus and minus 100 volts, as well as for 10 percent

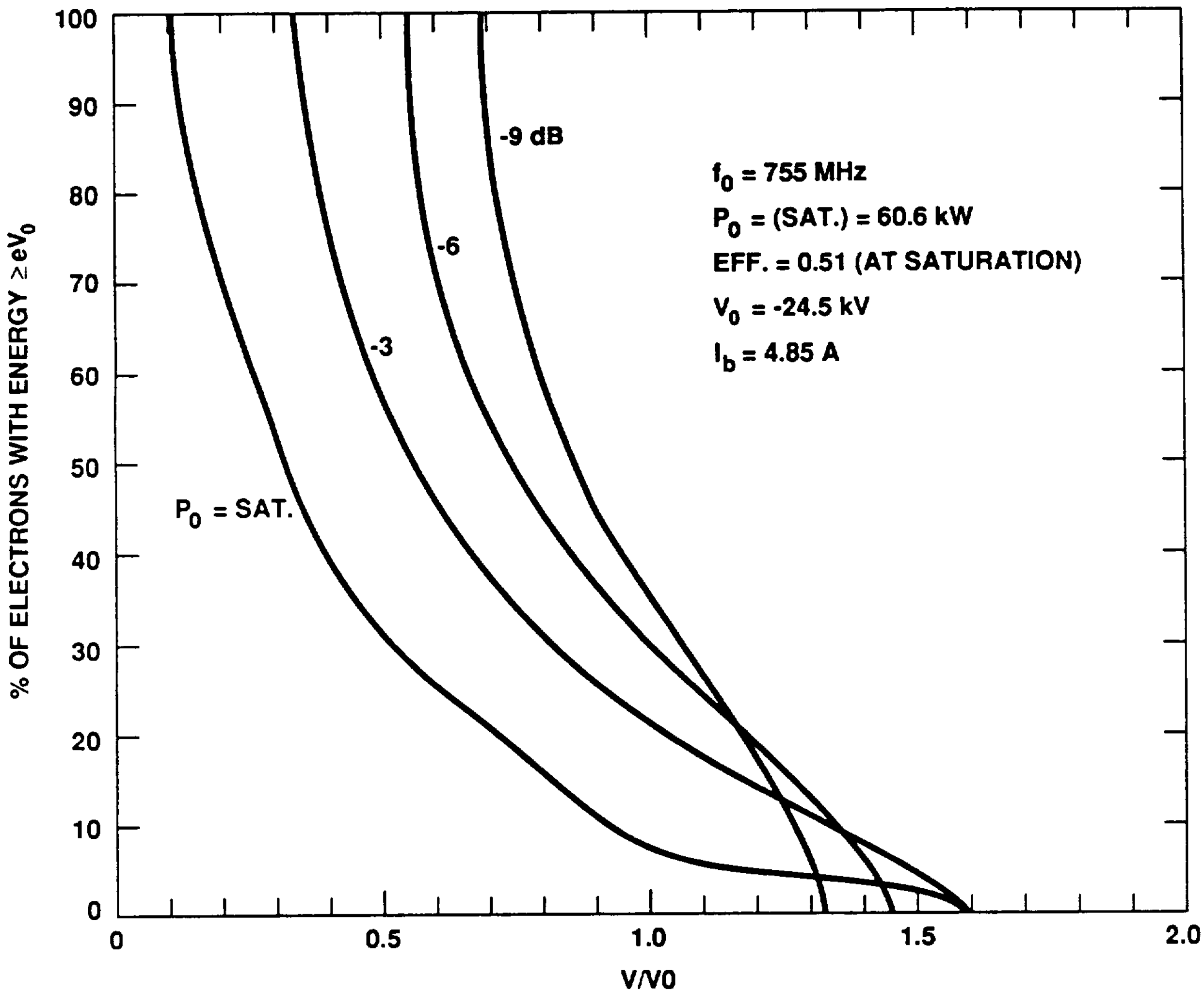

FIGURE 2. CALCULATED ENERGY DISTRIBUTION OF THE SPENT BEAM FOR THE VKP-7555 KLYSTRON

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25% SATURATION DESIGN 4G (3175)
HGUN 9/4/85 ITERATION 6

25% RF OUTPUT BEAM CONDITIONS WERE USED
TO DETERMINE THE SPACE CHARGE.

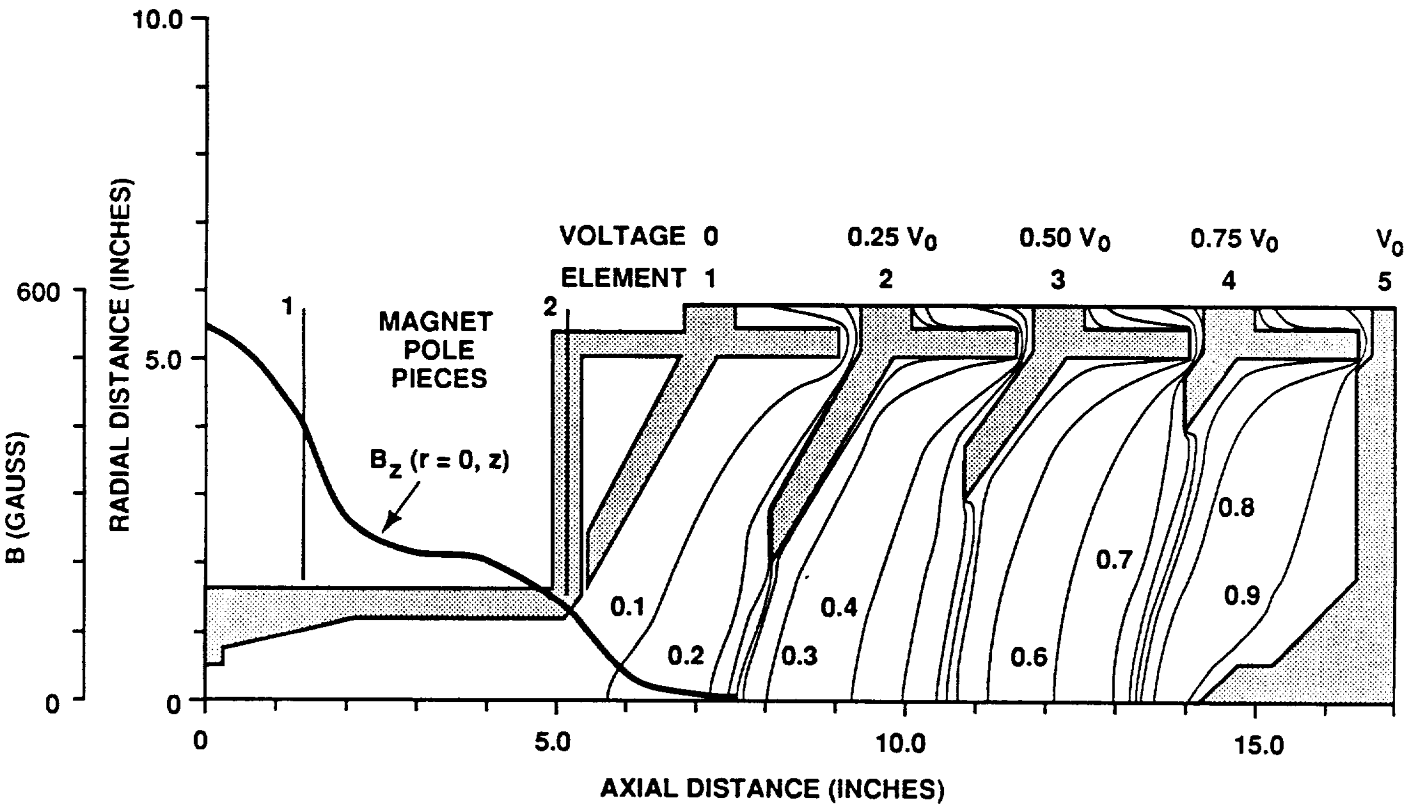

FIGURE 3. COLLECTOR ELECTRIC FIELD DISTRIBUTION

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increments of the cathode voltage. Electrode potentials were stepped at equally spaced intervals mainly to simplify power supply design; however, power recovery is close to optimum for the saturation condition due to the wide velocity distribution of the entering electrons. Other voltage distributions were analyzed and voltage patterns that were more negative did show improved performance for lower rf output conditions. Also incorporated in the design is the beam reconditioning as described by Kosmahl(ref. 4). Beam reconditioning is achieved by including a transition region between the rf interaction circuit and the collector with an intermediate magnetic field. Computer analysis allowed optimization of the refocuser geometry and the magnetic field. The optimized profile is shown in Figure 3.

Collector electron trajectories were determined for rf power levels of 90, 50, 25, and zero percent of saturated output power. Figures 4, 5, 6, and 7 show these data for the final design. The computed results provide current and power dissipation values for each electrode, assuming a secondary electron emission yield of zero. These current and power values were adjusted to account for an estimated effect of secondary electrons. A secondary yield ratio of 0.5 was used for this estimate as well as assuming that the secondaries go to the adjacent more positive electrode and start with low initial velocity. Based on these assumptions, the current and power distribution of Table 2 was determined. These data can be used to calculate tube efficiency which is plotted as a function of rf power indicated in Figure 8. Standard (undepressed) collector performance is included for comparison.

Table 2
Calculated Collector Current and Power Dissipated Distribution
Including Effect of Secondary Electrons

Beam Voltage = 24.5 kV
Beam Current = 4.85 A

• RF Output • Power		Current (A) Electrode Number						Collector Efficiency
		1	2	3	4	5		
0	KW	0	0	0.08	4.77	0	A	74.66%
15.8		0	0.47	2.44	1.38	0.56		69.8
31.9		0.27	2.13	0.97	1.03	0.45		63.0
57.8		2.08	1.32	0.64	0.50	0.31		53.7

		Dissipated Power (KW)					
0	kW	0	0	0.95	29.23	0	kW
15.8		0	3.62	10.78	8.35	8.34	
31.9		1.56	11.75	4.82	5.46	8.53	
57.8		10.05	5.03	3.14	2.78	7.26	

90% SATURATION DESIGN 4G (3177)
HGUN 9/4/85 ITERATION 6

COLLECTOR PERFORMANCE (WITHOUT SECONDARY ELECTRON EMISSON LOSSES)

ELECTRODE	V	I	P(COLL)	P(DISS.)	
5	0	5.044E-01	1.236E+04	6.063E+03	TOTAL DISSIPATED POWER = 2.676E+04
4	-6125	2.716E-01	4.991E+03	1.365E+03	TOTAL RECOVERED POWER = 3.446E+04
3	-12250	7.760E-01	9.506E+03	3.530E+03	SPENT BEAM POWER = 6.122E+04
2	-18375	1.242E+00	7.605E+03	5.008E+03	COLLECTOR EFFICIENCY = 56.29
1	-24500	2.056E+00	0.000E+00	1.079E+04	ELECTRONS RETURNED TO BODY = 5

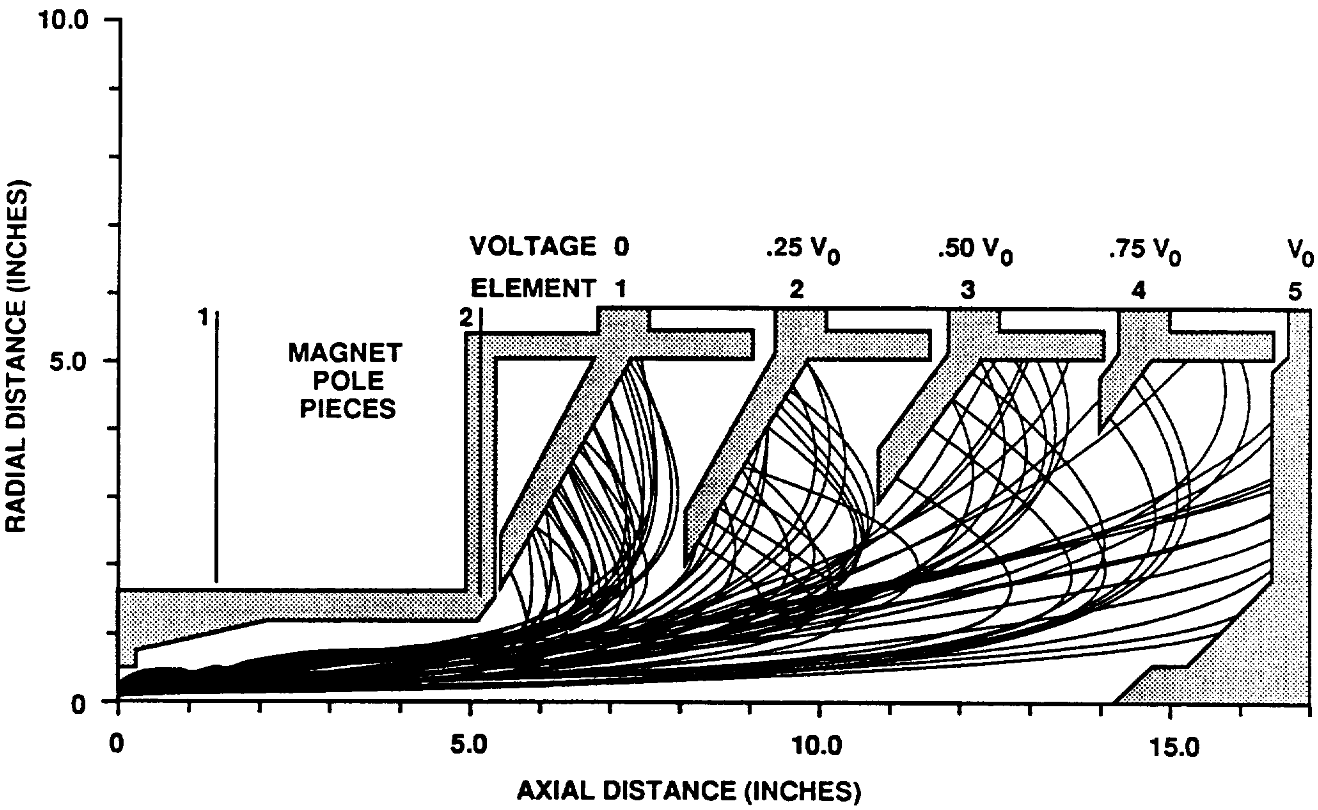

FIGURE 4. ELECTRON TRAJECTORIES FOR 90% SATURATION OUTPUT

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50% SATURATION DESIGN 4G (3176)
HGUN 9/4/85 ITERATION 6

COLLECTOR PERFORMANCE (WITHOUT SECONDARY ELECTRON EMISSION LOSSES)

ELECTRODE	V	I	P(COLL)	P(DISS.)
5	0	8.536E-01	2.091E+04	8.507E+03
4	-6125	5.044E-01	9.268E+03	2.756E+03
3	-12250	1.203E+00	1.473E+04	5.987E+03
2	-18375	2.018E+00	1.236E+04	1.125E+04
1	-24500	2.716E-01	0.000E+00	1.585E+03

TOTAL DISSIPATED POWER = 3.009E+04
TOTAL RECOVERED POWER = 5.727E+04
SPENT BEAM POWER = 8.736E+04
COLLECTOR EFFICIENCY = 65.56
ELECTRONS RETURNED TO BODY = 0

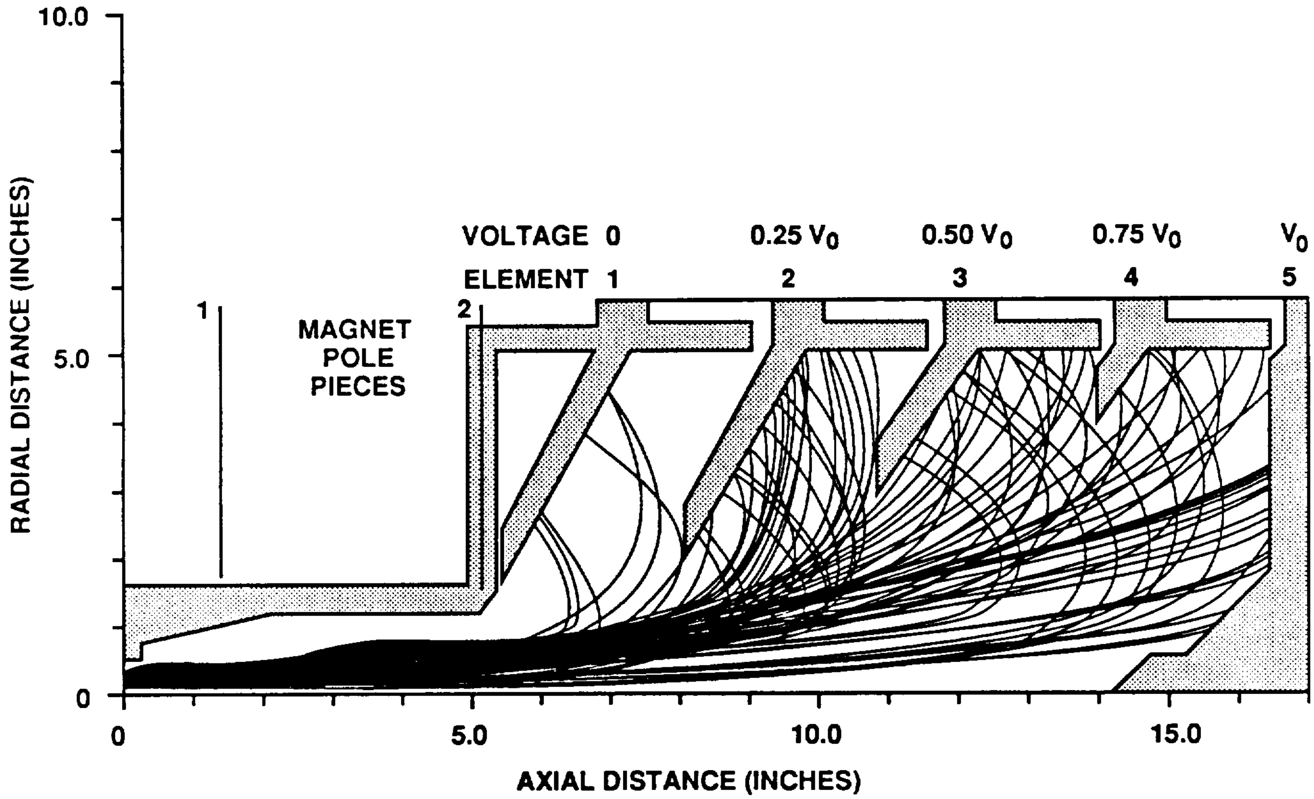

FIGURE 5. ELECTRON TRAJECTORIES FOR 50% SATURATION OUTPUT

25% SATURATION DESIGN 4G (3175)
HGUN 9/4/85 ITERATION 6

COLLECTOR PERFORMANCE (WITHOUT SECONDARY ELECTRON EMISSION LOSSES)

ELECTRODE	V	I	P(COLL)	P(DISS.)	
5	0	1.203E+00	2.947E+04	8.825E+03	TOTAL DISSIPATED POWER = 2.693E+04
4	6125	6.984E-01	1.283E+04	3.726E+03	TOTAL RECOVERED POWER = 7.652E+04
3	12250	2.638E+00	3.232E+04	1.187E+04	SPENT BEAM POWER = 1.035E+05
2	18375	3.104E-01	1.901E+03	2.512E+03	COLLECTOR EFFICIENCY = 73.97
1	24500	0.000E+00	0.000E+00	0.000E+00	ELECTRONS RETURNED TO BODY = 0

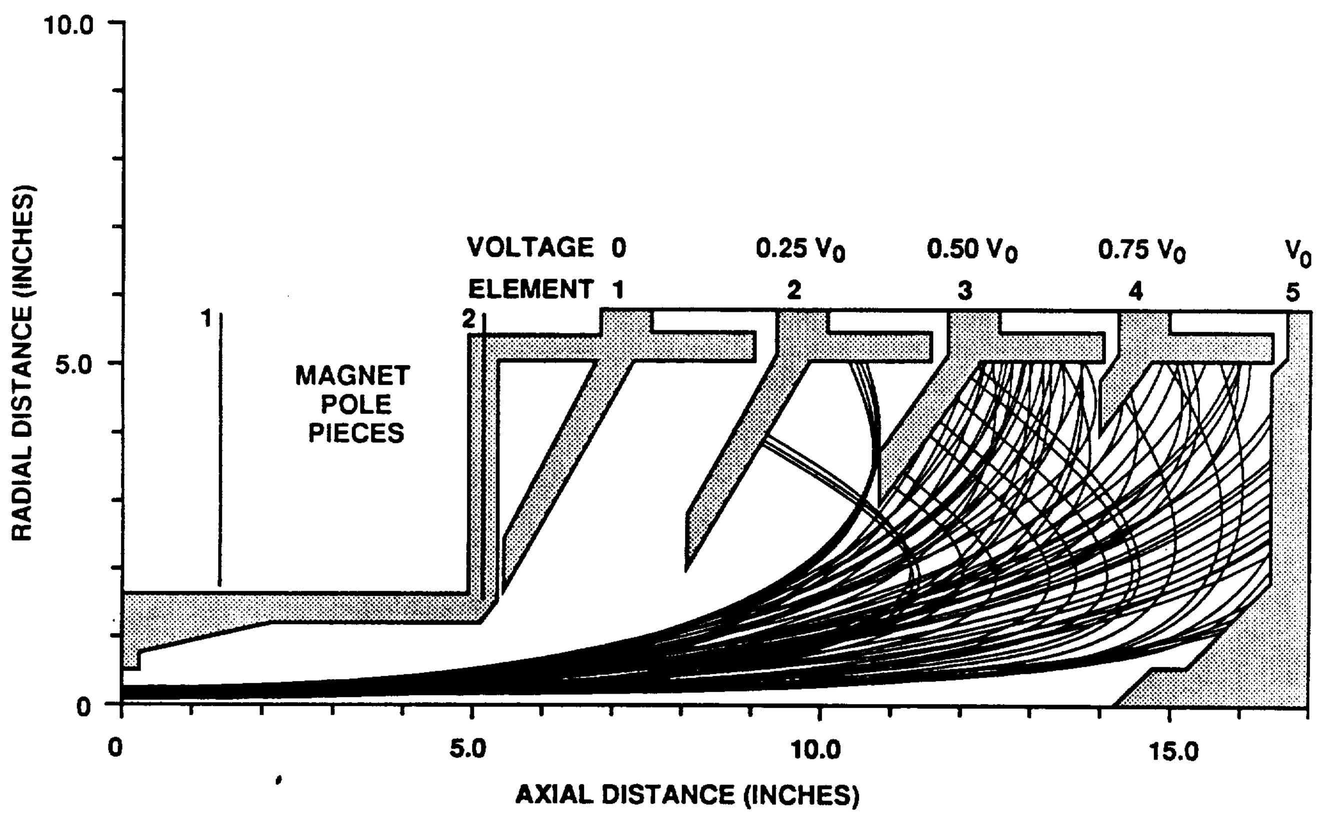

FIGURE 6. ELECTRON TRAJECTORIES FOR 25% SATURATION OUTPUT

DC BEAM DESIGN 4G (3182)

HGUN 9/4/85 ITERATION 6

COLLECTOR PERFORMANCE (WITHOUT SECONDARY ELECTRON EMISSION LOSSES)

ELECTRODE	V	I	P(COLL)	P(DISS.)
5	0	0.000E+00	0.000E+00	0.000E+00
4	-6125	4.772E+00	8.769E+04	2.923E+04
3	-12250	7.760E-02	9.506E+02	9.506E+02
2	-18375	0.000E+00	0.000E+00	0.000E+00
1	-24500	0.000E+00	0.000E+00	0.000E+00

TOTAL DISSIPATED POWER = 3.018E+04

TOTAL RECOVERED POWER = 8.864E+04

SPENT BEAM POWER = 1.188E+05

COLLECTOR EFFICIENCY = 74.60

ELECTRONS RETURNED TO BODY = 0

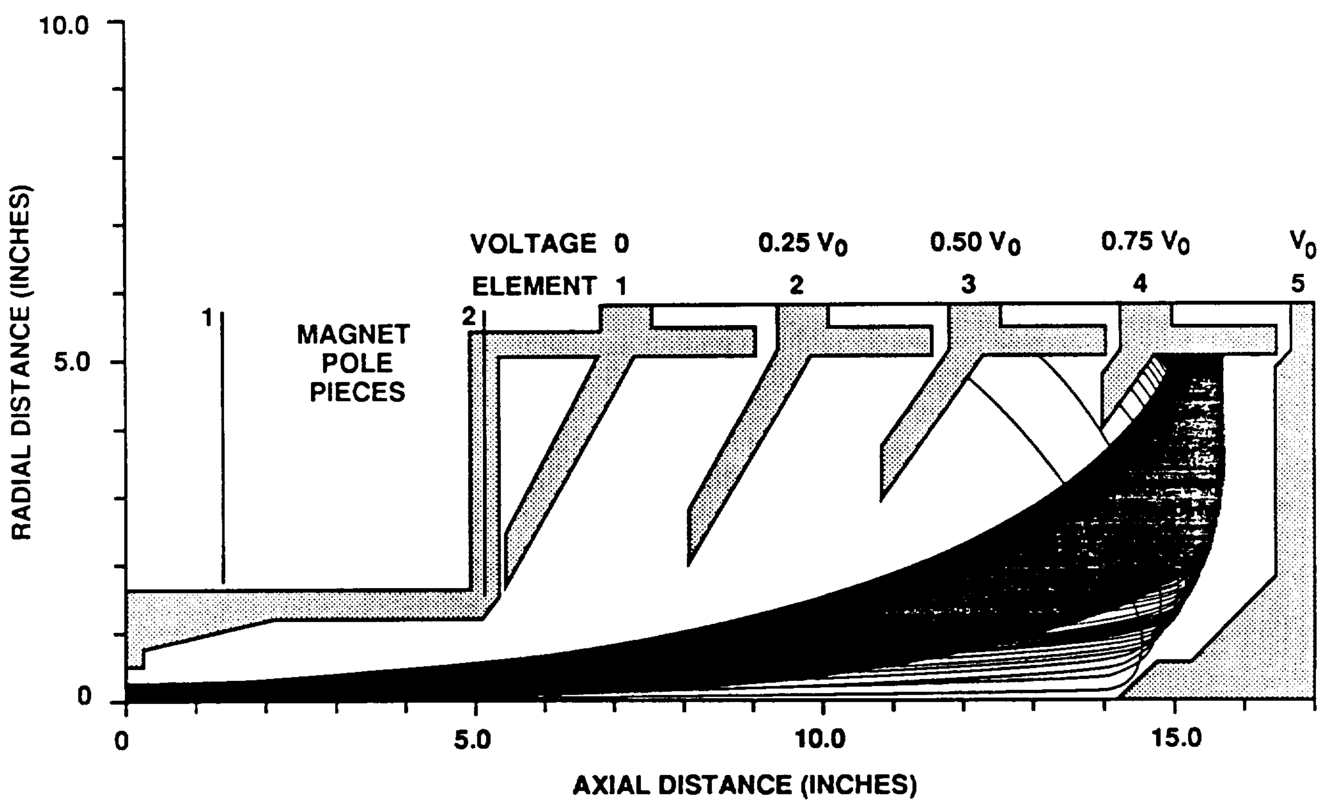

FIGURE 7. ELECTRON TRAJECTORIES FOR UNMODULATED BEAM

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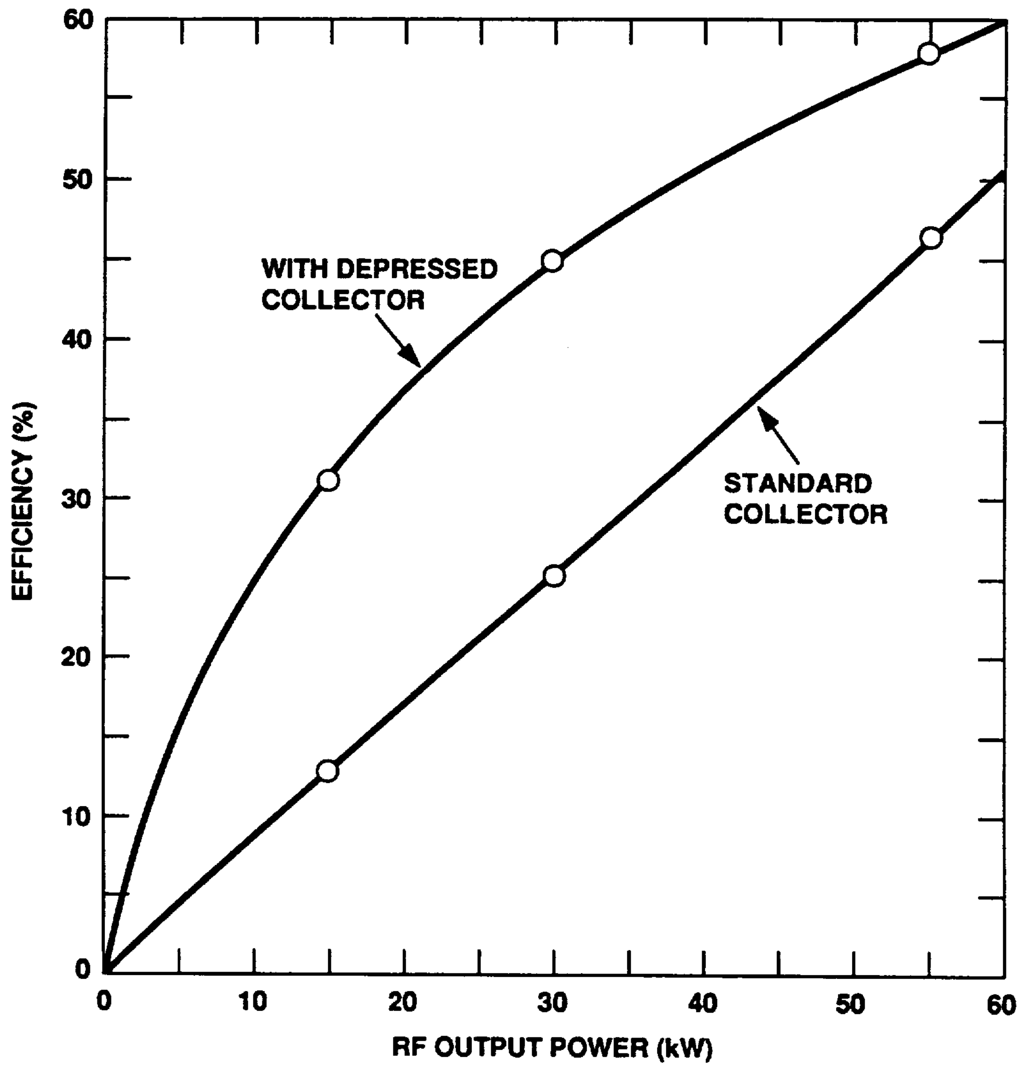

FIGURE 8. CALCULATED OVERALL TUBE EFFICIENCY AS A FUNCTION OF RF OUTPUT POWER

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3.0 MULTISTAGE DEPRESSED COLLECTOR ELECTRODE SURFACE COATING

An important part of the design effort was to develop a coating for the copper collector electrodes to minimize the adverse effects of secondary electrons.

It has been demonstrated that carbon provides a good surface for low secondary yield (ref. 5,6), but it was necessary to develop the technology to allow satisfactory coating of copper electrodes of large dimensions. A sputter coating facility was established with adequate capability for coating electrodes up to 16 inches in diameter.

A photograph of the coating equipment is shown in Figure 9.

Sample copper electrodes were coated with sputtered carbon and evaluated to determine the secondary yield characteristics. The measured secondary yield is shown in Figure 10 in comparison with other secondary suppression techniques. The average electron velocity on impact in the MDC is 3000 V; extrapolating the data of Figure 10 to that value indicates a secondary yield well under 0.5.

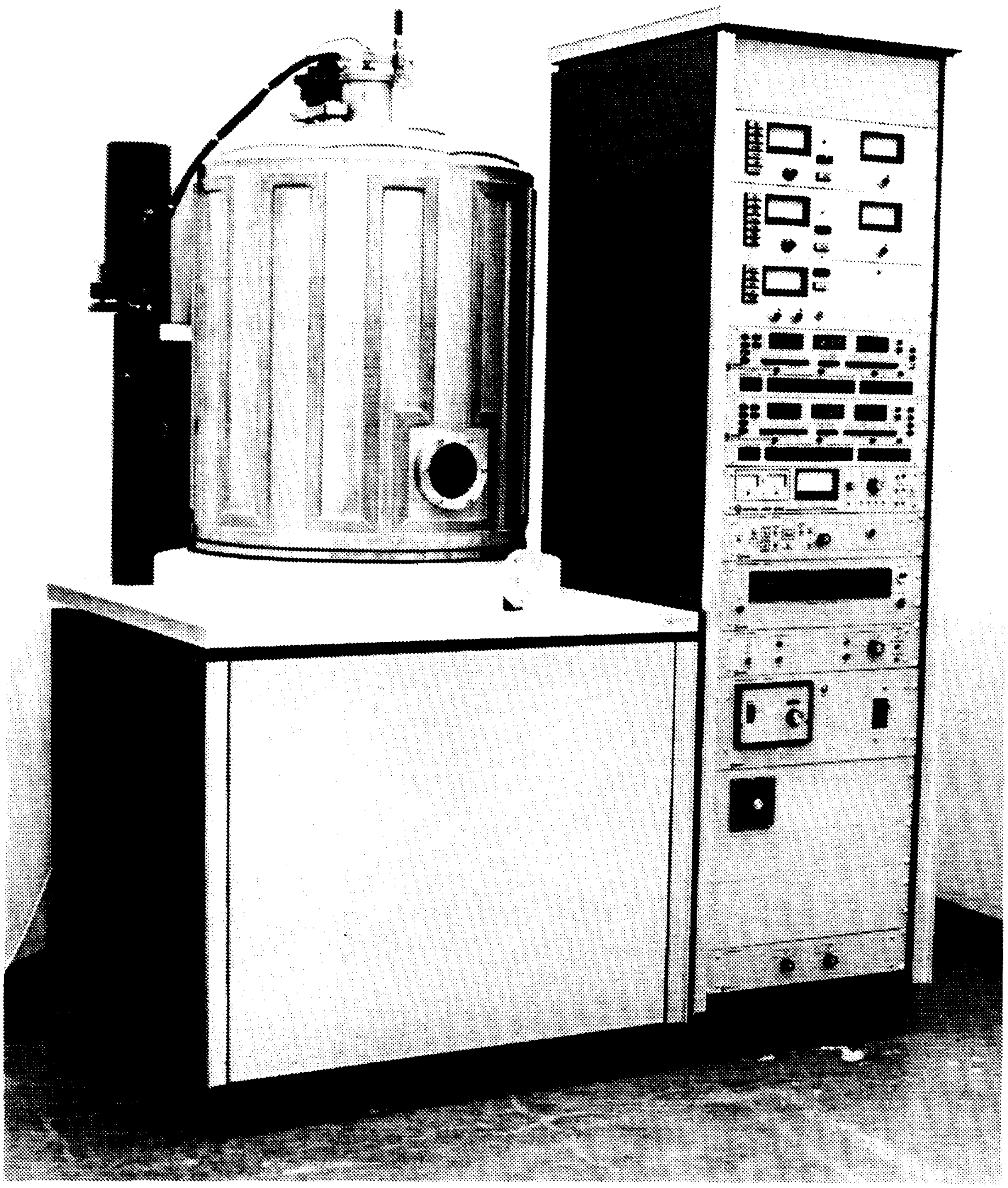

FIGURE 9. CARBON SPUTTERING EQUIPMENT
(VARIAN 3120 SYSTEM)

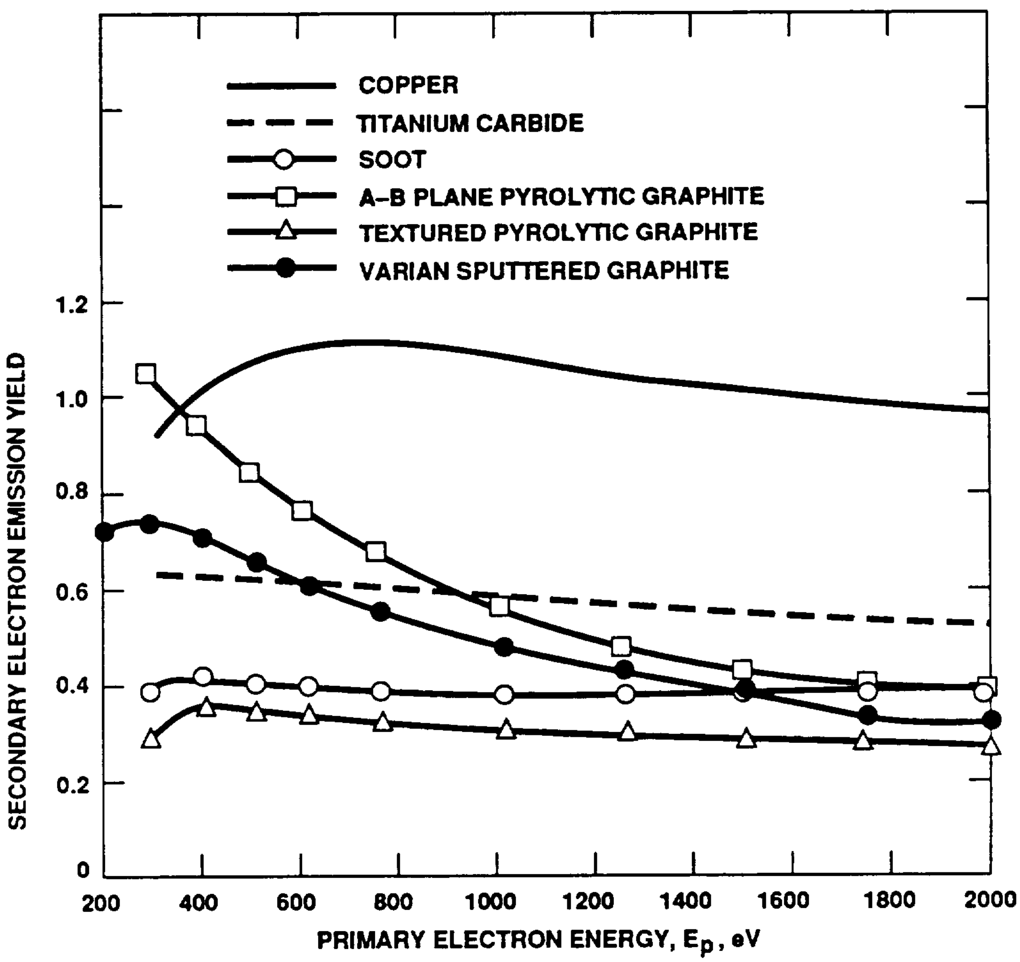

FIGURE 10. SECONDARY ELECTRON EMISSION YIELD AS A FUNCTION OF PRIMARY ELECTRON ENERGY

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4.0 COLLECTOR CONSTRUCTION

The collector design which resulted from the computer analysis effort is shown in Figure 11. The collector is composed of five copper electrodes mounted between ceramic rings to provide electrical insulation while completing the vacuum envelope. The electrodes are coated with a thin layer of carbon of 2 to 5 micron thickness, in the regions of electron impingement to minimize the adverse effect of secondary electrons. Each electrode contains passages for water cooling. Thermal analysis indicated that a water flow rate of 5 GPM was adequate for 30 kW average MDC dissipation calculated during the computer analysis effort. Located between the klystron interaction circuit and the collector is a refocusing electromagnet, wound directly onto the klystron.

A photograph of the partly assembled collector is shown in Figure 12. The rear electrode is shown to the side in order to show the internal construction of the collector. A construction problem was encountered which resulted in breakage of the small ceramic ring between the klystron and the first electrode. The breakage occurred during the heat cycle associated with vacuum processing. Evaluation of the problem resulted in a simple solution, but this process caused a significant program delay.

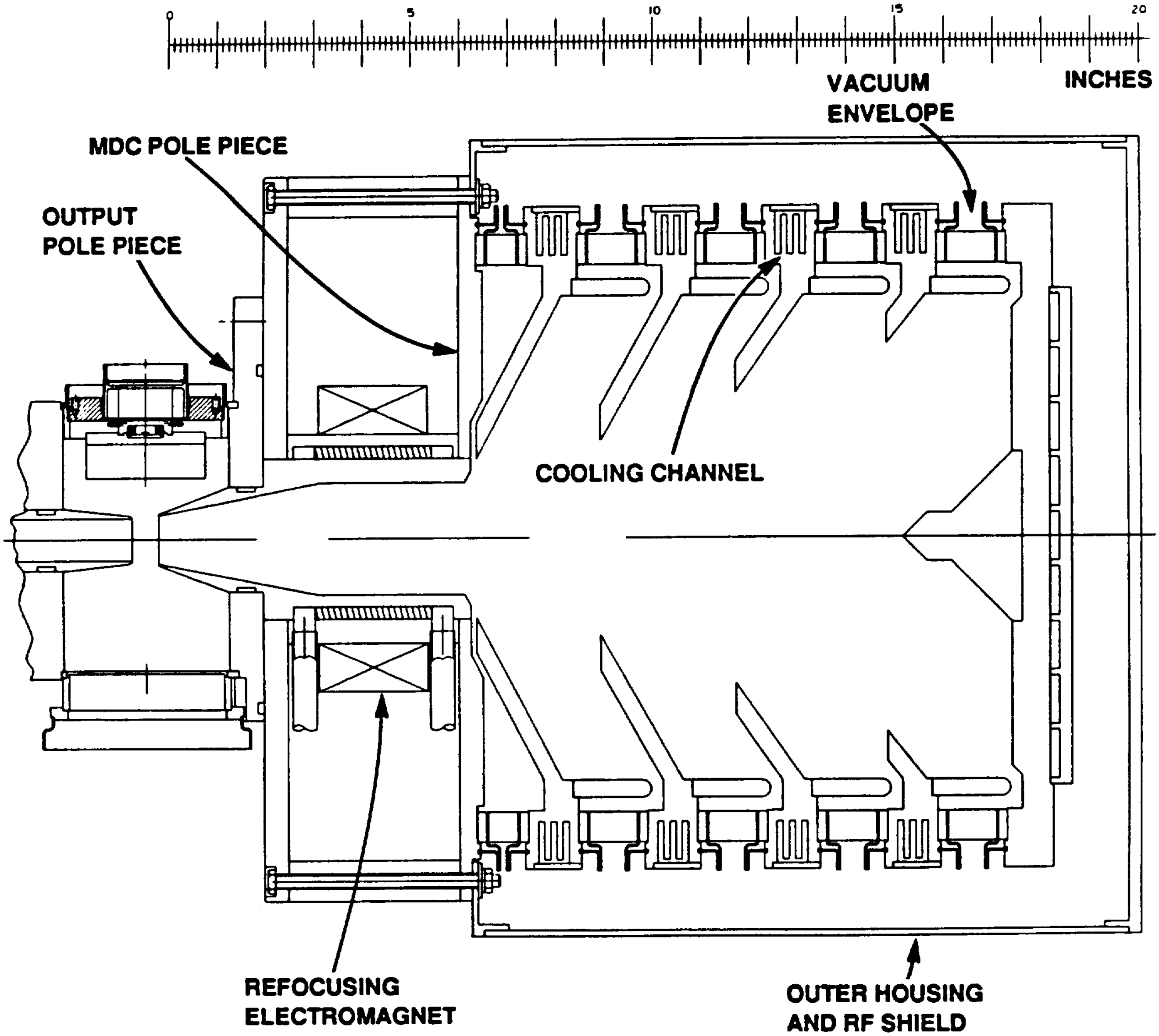

FIGURE 11. UHF-TV MDC DESIGN FOR EXPERIMENT #1

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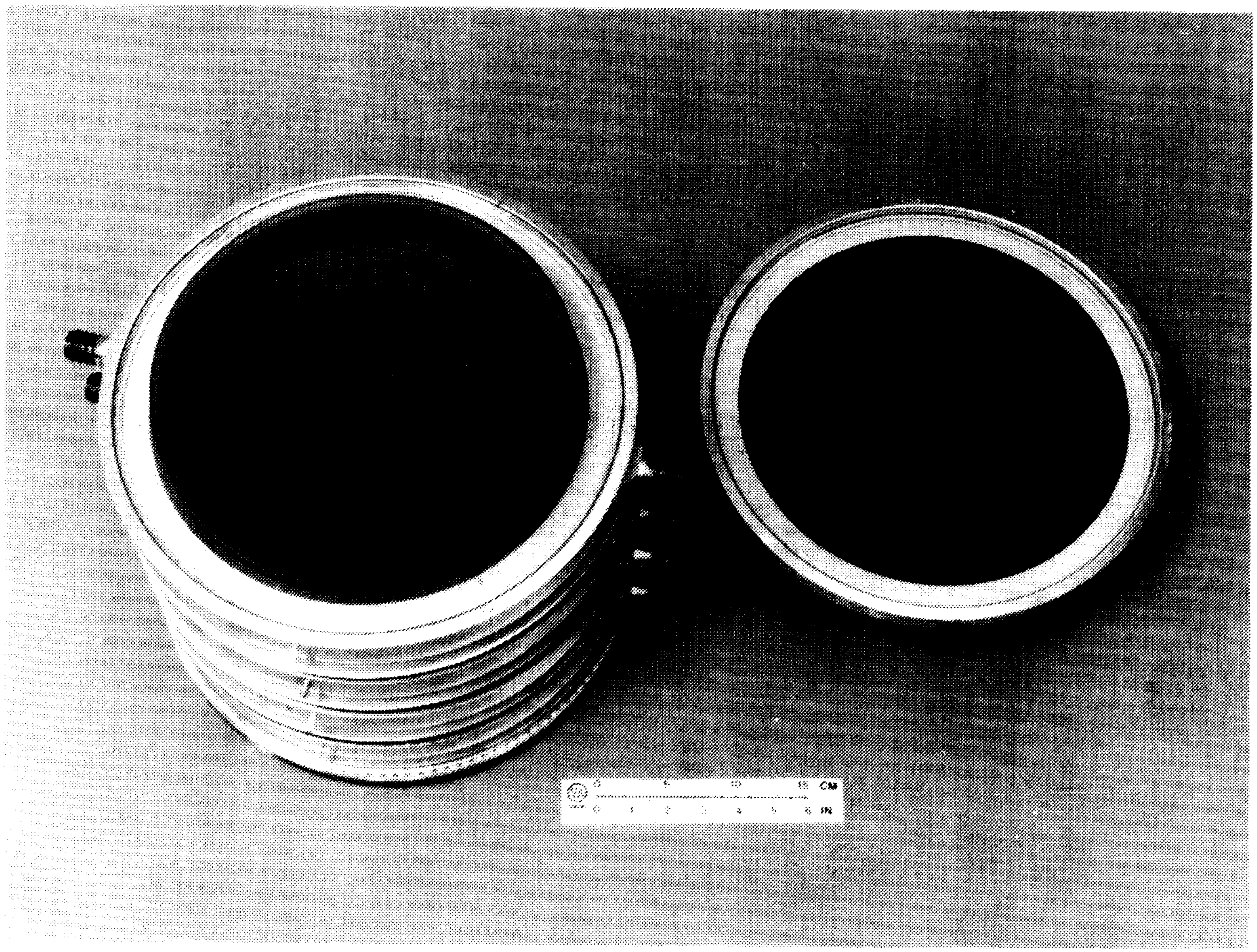

FIGURE 12. MULTISTAGE-DEPRESSED COLLECTOR PARTLY ASSEMBLED

5.0 KLYSTRON PERFORMANCE

Figure 13 is a photograph of the completed experimental klystron and MDC. Figure 14 shows the collector region with the collector shield partially removed to allow visibility of the collector elements.

Testing of the experimental klystron was conducted in a pulsed mode, 60 pulses per second of 16.7 μs duration. Subsequent CW tests have shown close agreement with the pulse data while demonstrating full power capability. Performance was measured over a wide range of operating conditions to give a complete characterization of the collector performance. Power supplies to operate this klystron could use either a parallel or series configuration as indicated in Figure 15. Although testing was conducted with a parallel arrangement, the results are presented for both configurations.

The first step in the tube evaluation was to determine the characteristics of the beam reconditioning region at the collector entrance. With no rf modulation on the beam, nearly all current should go to the next to the last electrode, I_4. Adjustment of the refocusing coil current allowed I_4 to be maximized to nearly full beam current; see Figure 16. The optimum value of coil current was also very close to the expected value. The refocusing coil has only 0.5 ohms resistance, so less than 20 watts of power is required for the normal operating current in the range of 4 to 6 amperes.

Measurements of the current distribution to the collector elements were performed as a function of the rf drive power. The results for normal operating conditions are shown in Figure 17. For no rf drive, essentially all the current goes to electrode 4 but as drive is increased, I_4 drops rapidly as I_3 increases, followed by I_2 and finally I_1. It is interesting to note that he current to electrode 5, which is at cathode potential, peaks at about 10 percent of the beam current at half output power. This is close to the predicted value and suggests that the secondary yield of the carbon coated collector surfaces is near the expected value of 0.4 as discussed in Section 3. Also, the body current is less than 2 percent of the beam current for all drive levels, but it does appear to contain a component of current proportional to I_5. Consequently, part of the body current could be backstreaming secondary electron current, a part of which could enter the drift tube and contribute to regeneration.

Particular attention was given to determining regeneration levels. Bandpass curves were measured, as shown in Figure 18, which represents a normal tuning pattern. In this

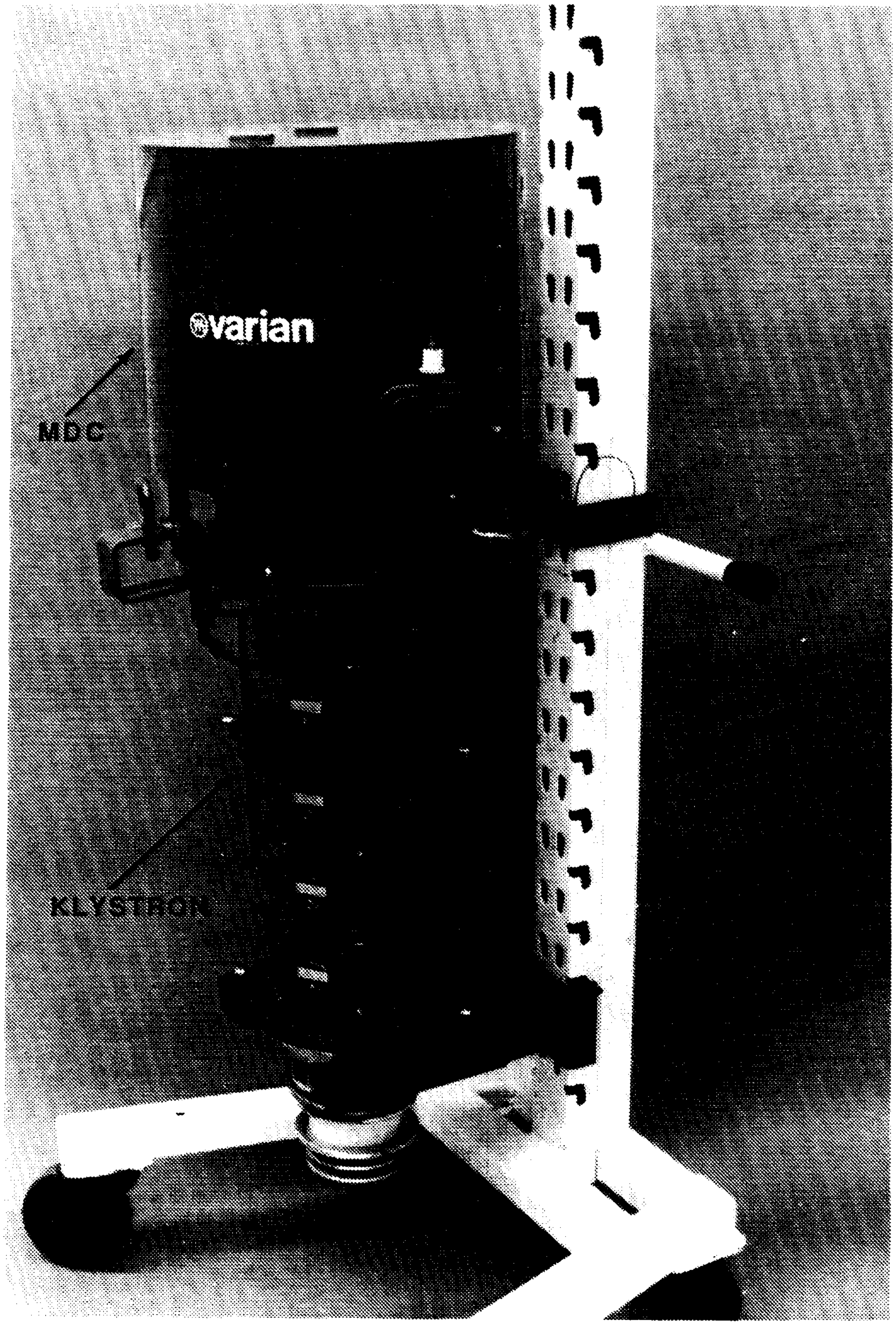

FIGURE 13. MULTISTAGE-DEPRESSED COLLECTOR WITH UHF KLYSTRON

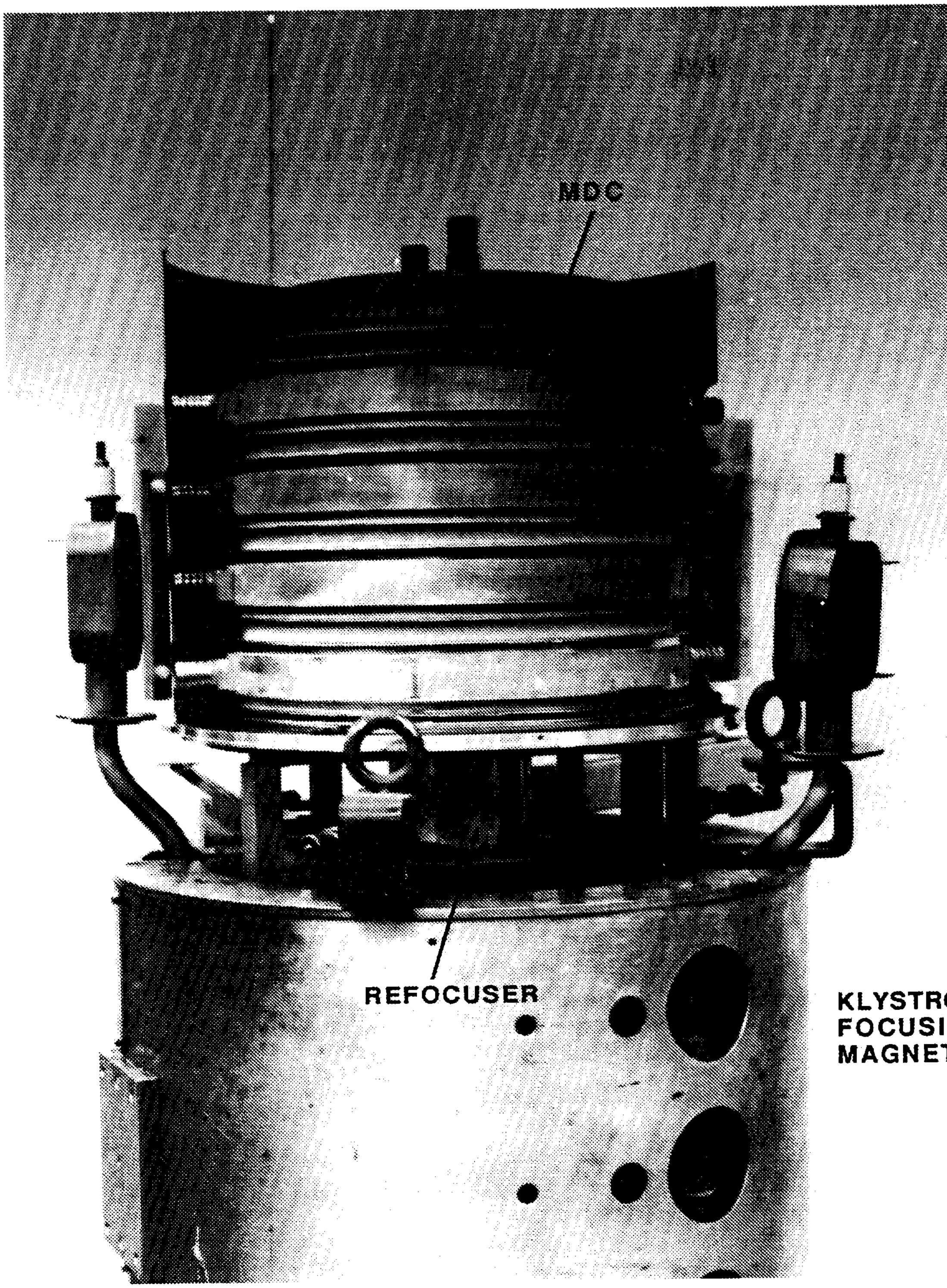

FIGURE 14. MULTISTAGE-DEPRESSED COLLECTOR REGION EXPOSED

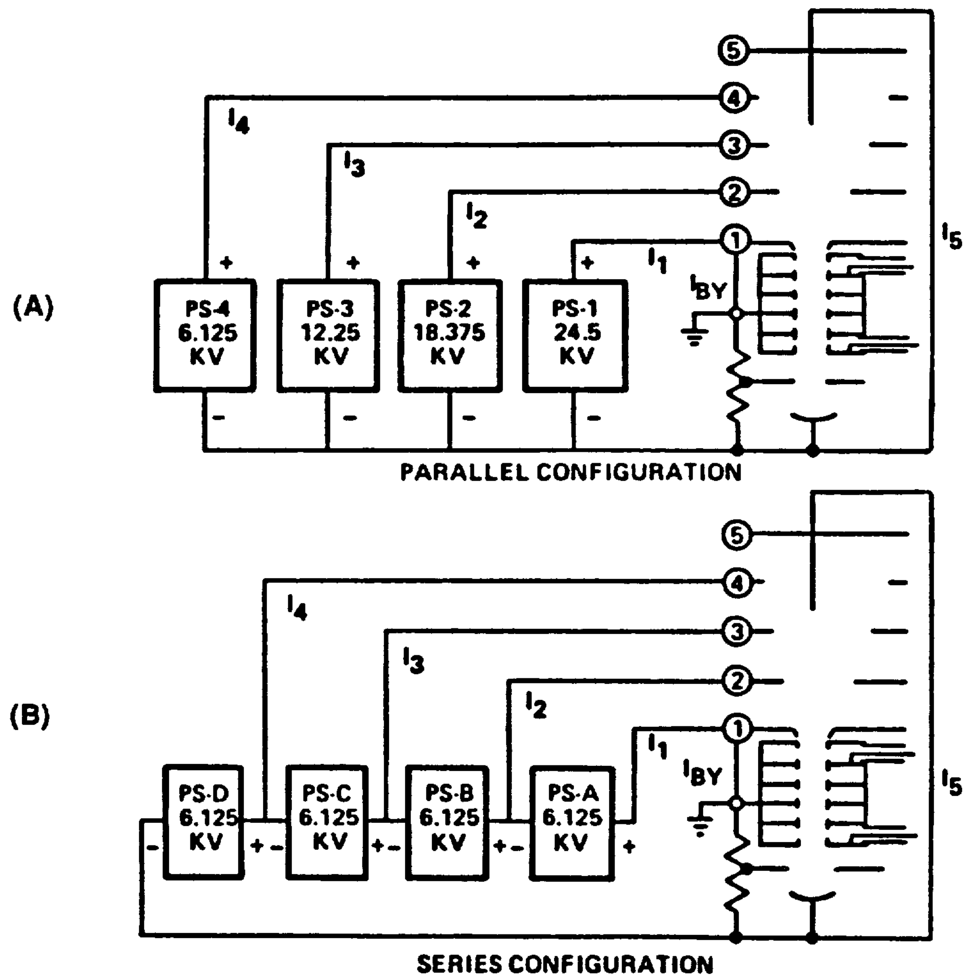

FIGURE 15. KLYSTRON AND MDC POWER SUPPLY SCHEMATICS

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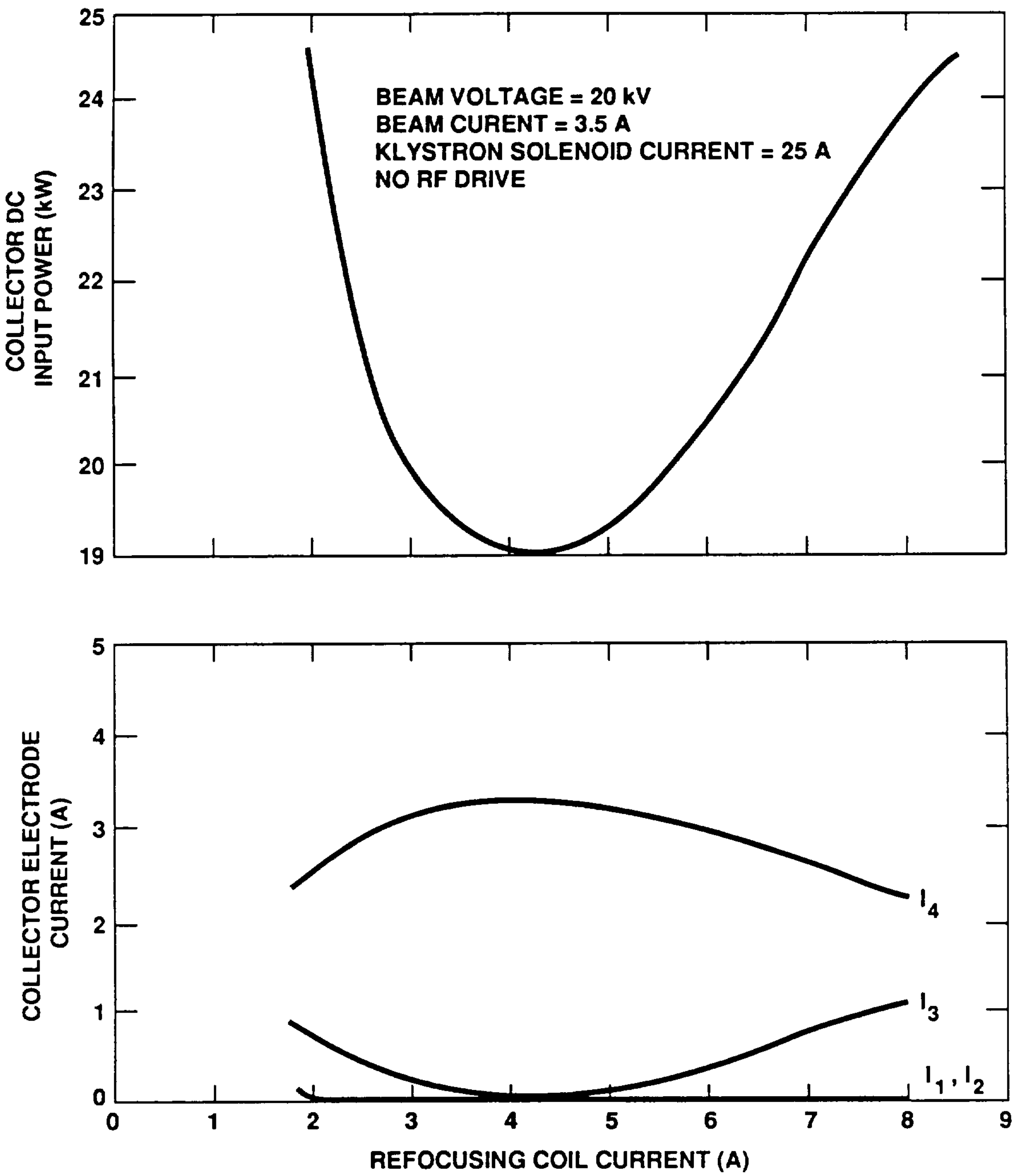

FIGURE 16. EFFECT OF REFOCUSING COIL CURRENT

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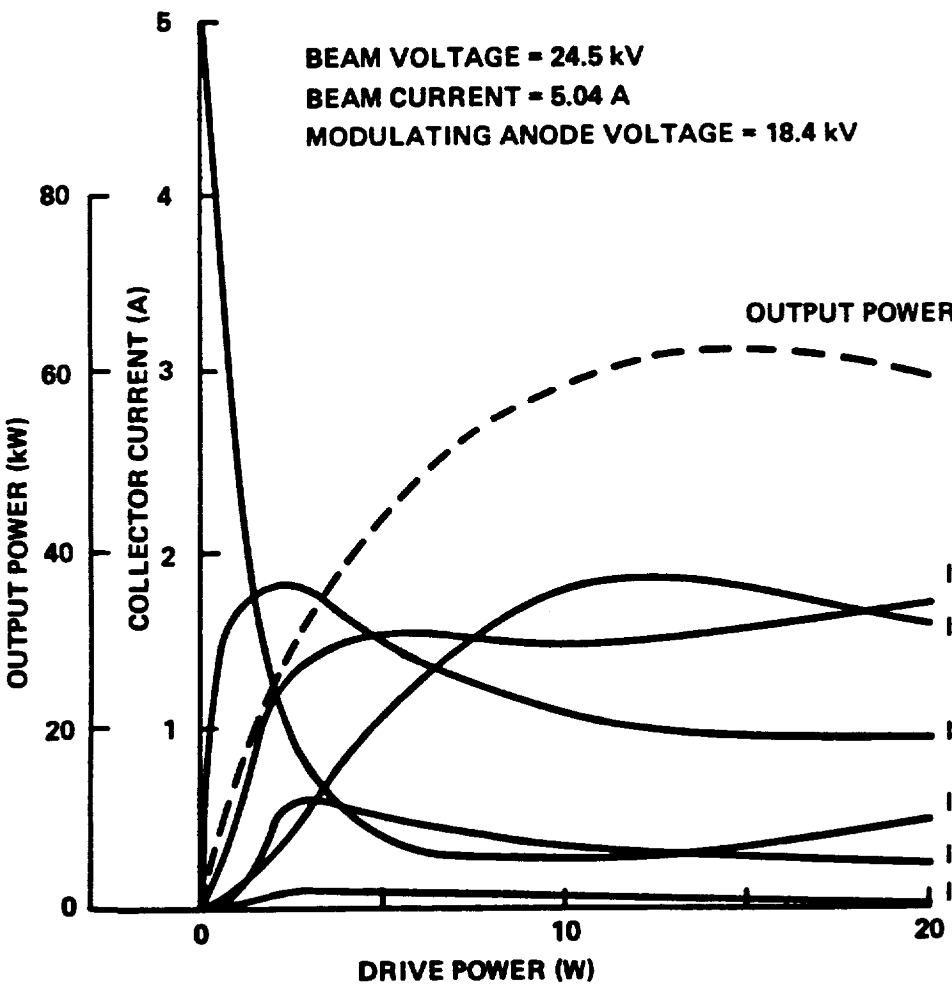

FIGURE 17. MDC CURRENT DISTRIBUTION AND RF OUTPUT POWER AS A FUNCTION OF RF DRIVE POWER

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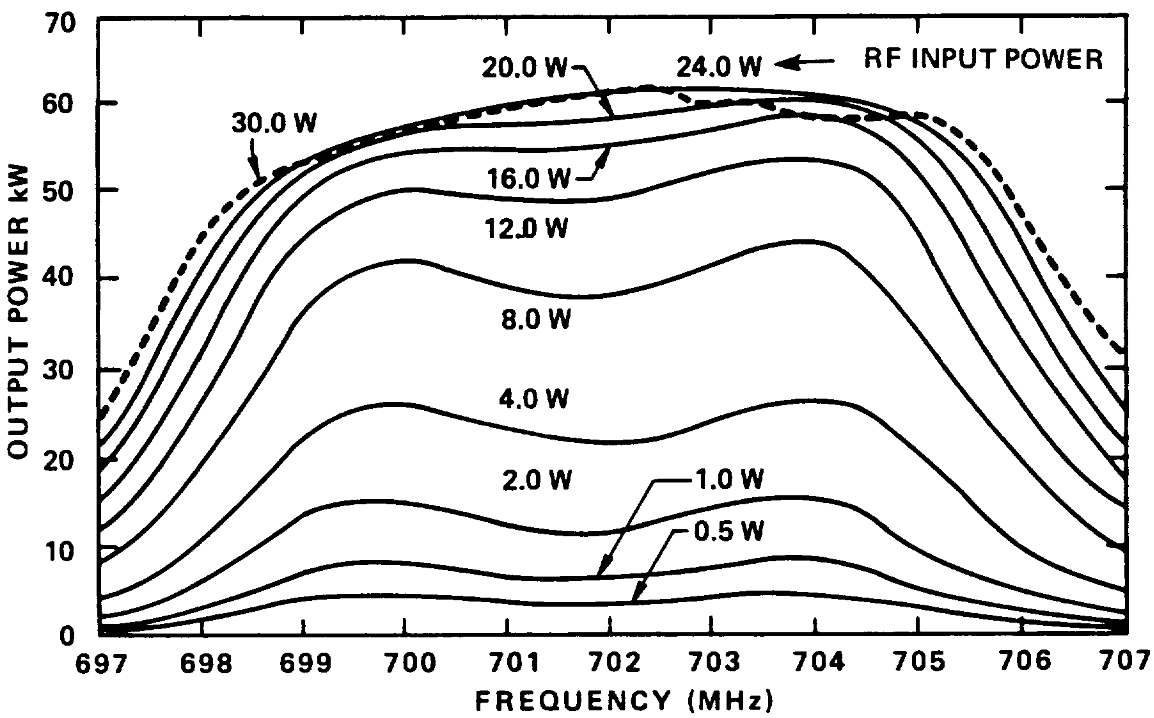

FIGURE 18. BANDPASS CHARACTERISTICS FOR A NORMALLY TUNED KLYSTRON

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case, regeneration is not evident since the gain, compared to the frequency and power, is constant and undisturbed. To determine the regeneration level, the klystron gain was increased by retuning for narrower bandwidth. The data of Figure 19 were obtained for a small-signal gain level of 60 dB. At this point, regeneration effects are clearly evident even though operation is stable with no oscillations.

The measured klystron efficiency, as a function of rf output power is shown in Figure 20. The measured value compares closely with the previously calculated value which supports the accuracy of our computer modeling technique.

Collector efficiency was also determined; this is the ratio of recovered power to spent beam power. For this analysis, only rf output power, collector power, and beam input power are considered. RF circuit losses and beam interception losses were neglected since they each contribute less than 1 percent of the total power. Figure 21 shows the measured values compared with those previously calculated. Close agreement shows here as well.

Also determined were the current and power requirements for the power supply configurations shown in Figure 15. The values for the various rf output conditions to simulate television operation are listed in Table 3. The corresponding output power values are: for saturated output, 60 kW; black picture, 30 kW; average picture, 10 kW; white picture, 1 kW; no drive, 0 kW. These results define the requirements for a compatible power supply. One value should be noted: the power consumption for an average TV picture is 51.8 kW, which can be compared with 118 kW for a klystron with a standard collector. Consequently, the goal for reducing power consumption to less than half has been accomplished.

Outgassing of the collector elements was significantly more severe than typical for standard undepressed collectors. The outgassing is attributed to absorbed gases on the carbon coating and caused prolonged processing of the tube. Subsequent tubes were equipped with an extra VacIon® pump which was used during the conditioning period. By incorporating improved vacuum pumping along with increased processing time, satisfactory vacuum levels have been achieved.

Successful demonstration of the klystron and depressed collector performance marked the completion of the development program.

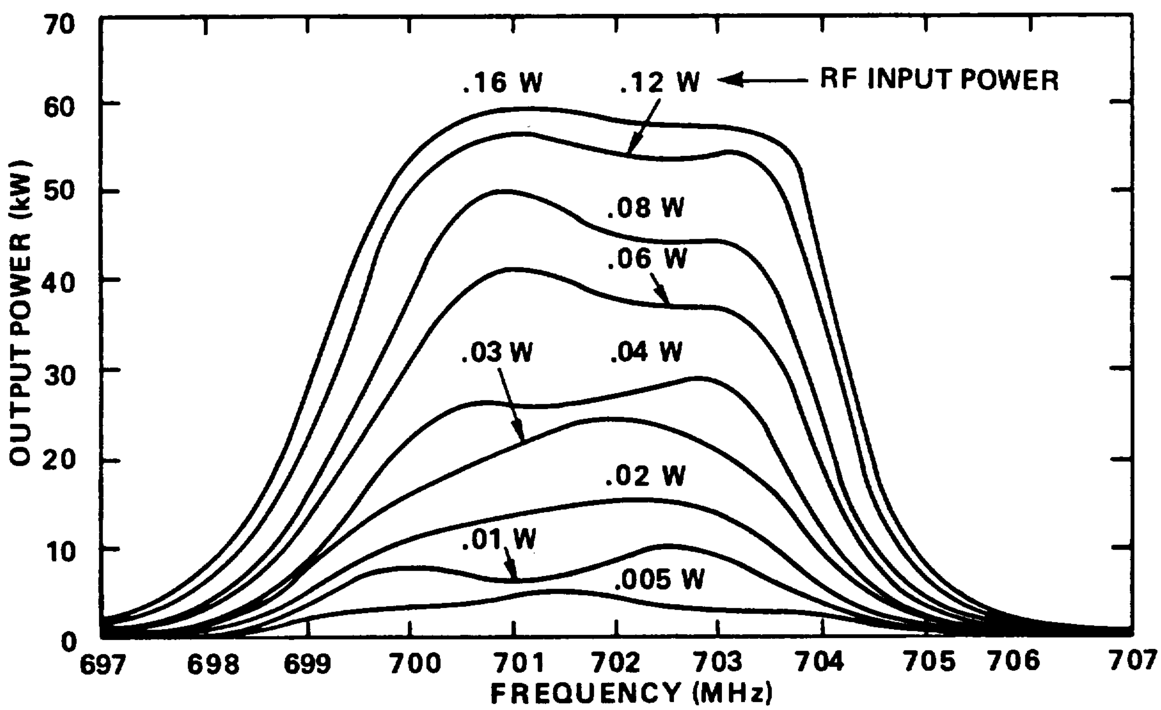

FIGURE 19. BANDPASS CHARACTERISTICS FOR A KLYSTRON TUNED FOR HIGH GAIN

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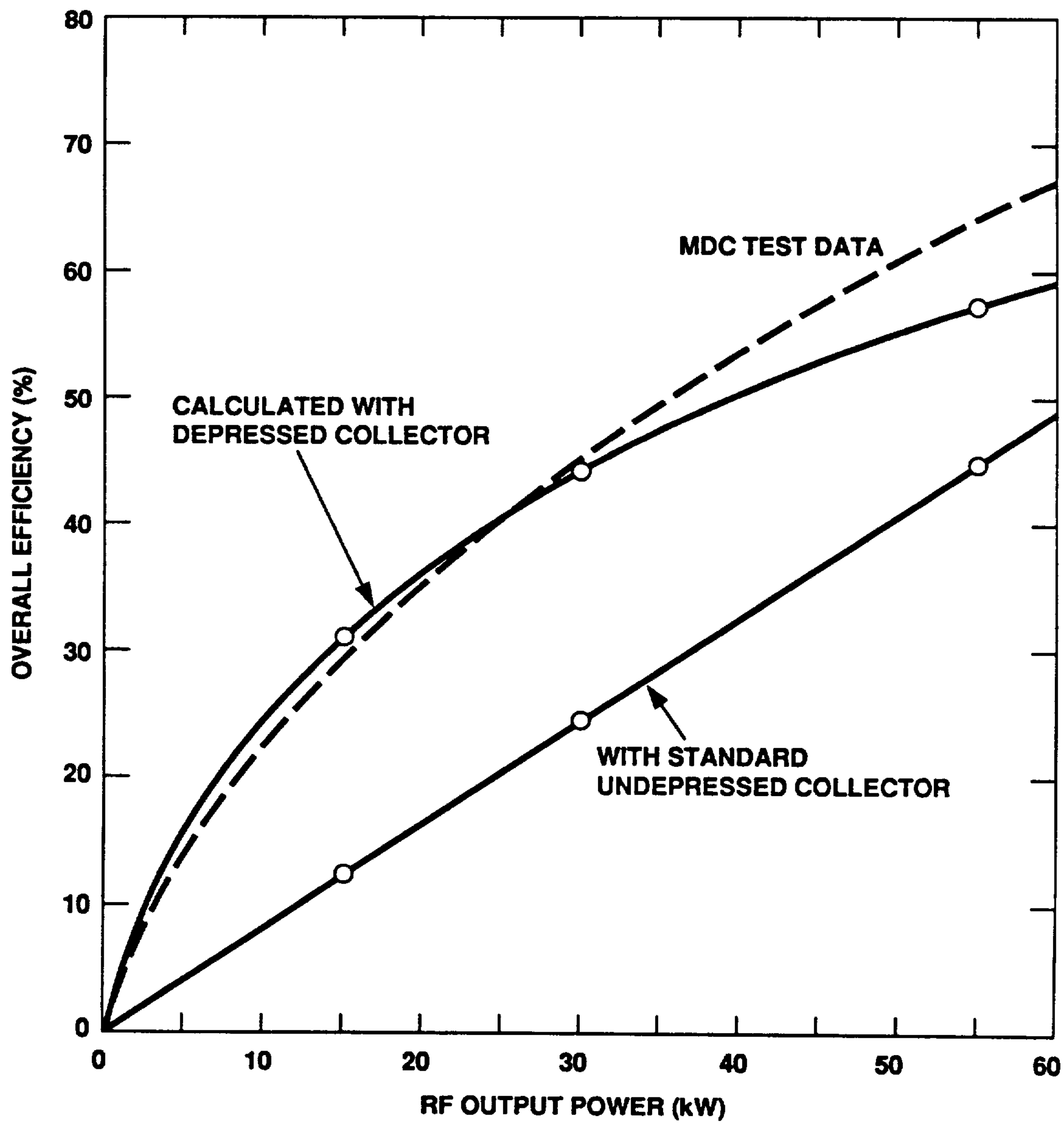

FIGURE 20. OVERALL TUBE EFFICIENCY AS A FUNCTION OF RF OUTPUT POWER

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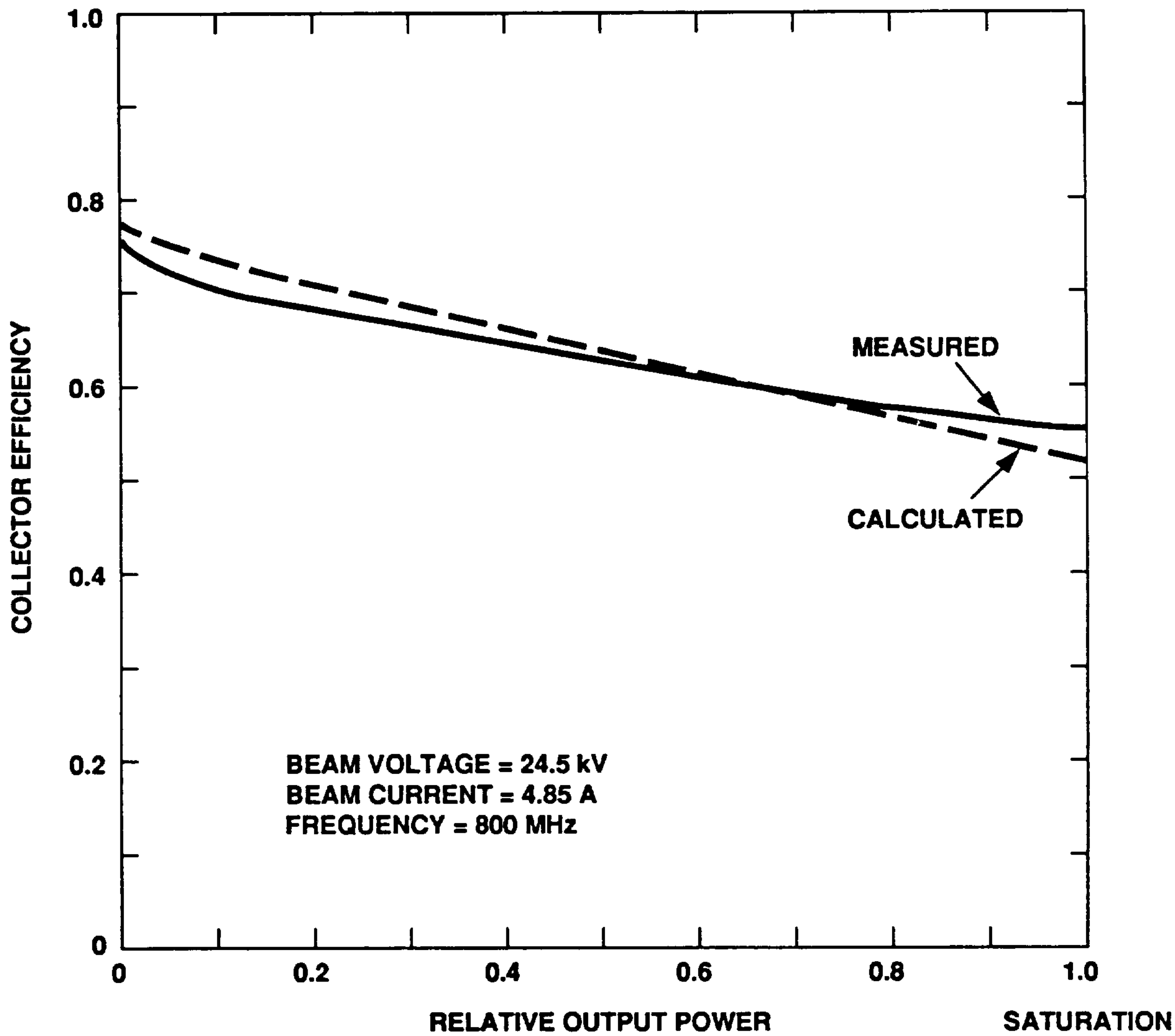

FIGURE 21. MDC KLYSTRON COLLECTOR EFFICIENCY AS A FUNCTION OF RELATIVE RF OUTPUT

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Table 3

Power Supply Current and DC Input Power Requirements

POWER SUPPLY		FOR TEST CONDITIONS		FOR TV SERVICE			
		SATURATED OUTPUT	NO DRIVE	BLACK PICTURE	AVERAGE PICTURE	WHITE PICTURE	
PS-1 24.5 KV	CURRENT	1.85	0.01	0.530	0.274	0.244	A
	POWER	45.33	0.25	12.99	6.71	5.99	kW
PS-2 18.375 KV	CURRENT	1.60	0.04	1.336	0.602	0.419	A
	POWER	29.40	0.74	24.54	11.07	7.70	kW
PS-3 12.25 KV	CURRENT	0.95	0.17	1.760	1.526	0.778	A
	POWER	11.64	2.08	21.56	18.69	9.53	kW
PS-4 6.125 KV	CURRENT	0.37	4.82	0.900	2.513	3.464	A
	POWER	2.27	29.52	5.51	15.39	21.22	kW
TOTAL INPUT POWER		88.64	32.59	64.60	51.86	44.44	kW

SERIES CASE

POWER SUPPLY		FOR TEST CONDITIONS		FOR TV SERVICE			
		SATURATED OUTPUT	NO DRIVE	BLACK PICTURE	AVERAGE PICTURE	WHITE PICTURE	
PS-A 6.125 KV	CURRENT	1.85	0.01	0.531	0.274	0.245	A
	POWER	11.33	0.06	3.25	1.68	1.50	kW
PS-B 6.125 KV	CURRENT	3.45	0.05	1.866	0.877	0.664	A
	POWER	21.13	0.31	11.43	5.37	4.07	kW
PS-C 6.125 KV	CURRENT	4.40	0.22	3.626	2.403	1.442	A
	POWER	26.95	1.35	22.21	14.72	8.83	kW
PS-D 6.125 KV	CURRENT	4.77	5.04	4.526	4.906	4.906	A
	POWER	29.22	30.87	27.72	30.05	30.05	kW
TOTAL INPUT POWER		88.63	32.59	64.61	51.82	44.46	kW

6.0 ADDITIONAL DEPRESSED COLLECTOR ACCOMPLISHMENTS

Varian has applied the MDC design to another UHF-TV klystron, a four-cavity amplifier of external cavity design. This klystron has been designated the VKP-7990. Preliminary technical data for this klystron are included in Appendix B. Two tubes have been constructed and evaluated. These tubes perform similarly to the experimental model described here. In addition, one of these tubes has operated in a CW power supply under simulated television conditions and has demonstrated satisfactory performance.

7.0 CONCLUSIONS

Test results for the MDC klystron are very encouraging. Power recovery compares closely with the predicted values and overall performance meets our expectations.

Computer-aided design techniques were applied successfully to this program. This design technique allowed consideration of numerous potential designs to select an optimum. Compared with the traditional design approach of building and evaluating experimental test models, this analytic approach allowed reaching an optimum design in a prompt and less costly manner. In addition, the analytic results provide a much greater insight into the details of tube performance.

Coating techniques for achieving low secondary yield surfaces were developed, with special capability for treating large surface areas.

Performance of the experimental klystron appears satisfactory for the television application. Regeneration due to returned electrons appears acceptable, allowing gain of over 40 dB. Outgassing of the carbon coated collector surfaces is noticeable but tolerable.

To date, three MDC klystrons have been produced. These tubes have been supplied as developmental models to transmitter manufacturers for evaluation in TV service.

Successful performance in television transmitter service will lead to new klystron transmitters with efficiency values well beyond what is presently available. In addition, application of MDC technology to other klystron amplifiers holds promise of greatly improved efficiency for numerous radar and industrial applications as well as for communication systems.

APPENDIX A
VKP-7555S TECHNICAL REPORT

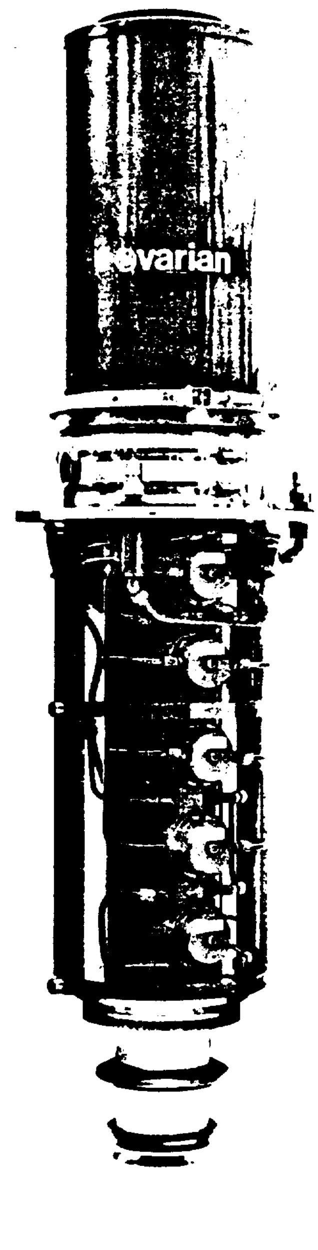
VKP-7555S

CW KLYSTRON AMPLIFIER

694-850 MHz

DESCRIPTION

The VKP-7555S is an integral five-cavity, vapor-cooled klystron for use as a final amplifier in both visual and aural sections of UHF-TV transmitters. This klystron covers the frequency range of 694 to 850 megahertz. It offers the user improved linearity and higher operating efficiency. The special design of this tube permits multiplexing both visual and aural signals at 50 to 75 percent of the visual-only rating, depending upon the means of signal generation and linearity correction employed. The VKP-7555S has the capability of being tuned as an "H" utilizing current lower power drivers. It can be retuned for "S" operation when higher drive power is provided. This klystron is mechanically interchangeable with existing VA-955H Klystrons.



FEATURES

High Efficiency — 52% minimum saturated efficiency for reliable, long-life performance. Considerably higher peak-of-sync efficiency can be achieved when mod-anode pulsing is employed. Actual peak-of-sync data can be obtained from the original equipment manufacturer.

Ample Bandwidth — One-dB is at least 6 MHz over the tuning range. Output power will not vary more than ±1.0 dB over the range of -1.0 MHz to +5.0 MHz from the visual carrier frequency and over the power levels from white to black.

Vapor Cooling — Reduces equipment size, noise, and cost: only 2 gal/min (0.12 ℓ/s) water flow required.

Modulating Anode — Provides means for aural power control using the visual beam power supply.

Multiplex Operation — Operation at 25 kW or more in full multiplex.

Simple Installation and Operation — Each tube is factory tuned to a specified frequency but is tunable over its entire frequency range. The electromagnet operates from a single power supply. Installing the tube is made easy by rollers on the tube which mate with channels in the electromagnet. Mechanically interchangeable with existing VA-955H Klystrons.

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GENERAL CHARACTERISTICS[1]

ELECTRICAL

Frequency Range	694 to 850 MHz
Heater Voltage, typ	7.0 Vac
Heater Current, typ	17 Aac
Heater Surge Current, max	30 Aac
Heater Warm-up Time, min	5 min
Focusing	Electromagnet
Electromagnet Voltage, max	145 Vdc
Electromagnet Current, max	32 Adc
2nd Cavity Load, Max	200 Watts

PHYSICAL

Dimensions	See Outline Drawing
Weight, approx	
VKP-7555S	257 lb/117 kg
VA-1952H & VA-1955H Series Electromagnets	320 lb/145 kg
Mounting Position	Cathode down
Cooling	
Tube	Water Vapor and Forced Air
Electromagnet	Water
Water Inlet Temperature,[2] max	70 °C

OPERATING CONDITIONS AND RATINGS[1]

	VKP-7555S[5,6] Typical Operation	Maximum Ratings[4]	
Frequency, visual	753	---	MHz
Output, saturated	62	---	kW
Output, peak-of-sync	58	---	kW
Drive Power, peak-of-sync	15	---	W
Gain, peak-of-sync	36	---	dB
Efficiency, saturated	52	---	%
Bandwidth, 1-dB	6	---	MHz
Beam Voltage	24.5	26	kVdc
Beam Current	4.8	8	Adc
Body Current	10	100	mAdc
Modulating Anode Voltage	17	26	kVdc
Modulating Anode Current	0.5	5	mAdc
Focusing Current	30	32	Adc
Load VSWR	<1.1:1	1.5:1	
Collector Temperature[3]	130	145°	C

COOLING

Distilled water is the preferred coolant. Water purity should be maintained in accordance with the information contained in the Varian Application Engineering Bulletin AEB-31. In addition, at least 200 lb/h (90.8 kg/h) of clean dry air should be directed at the cathode. For additional information, contact the nearest Varian Sales Office, or the Varian Microwave Tube Division, Palo Alto, California.

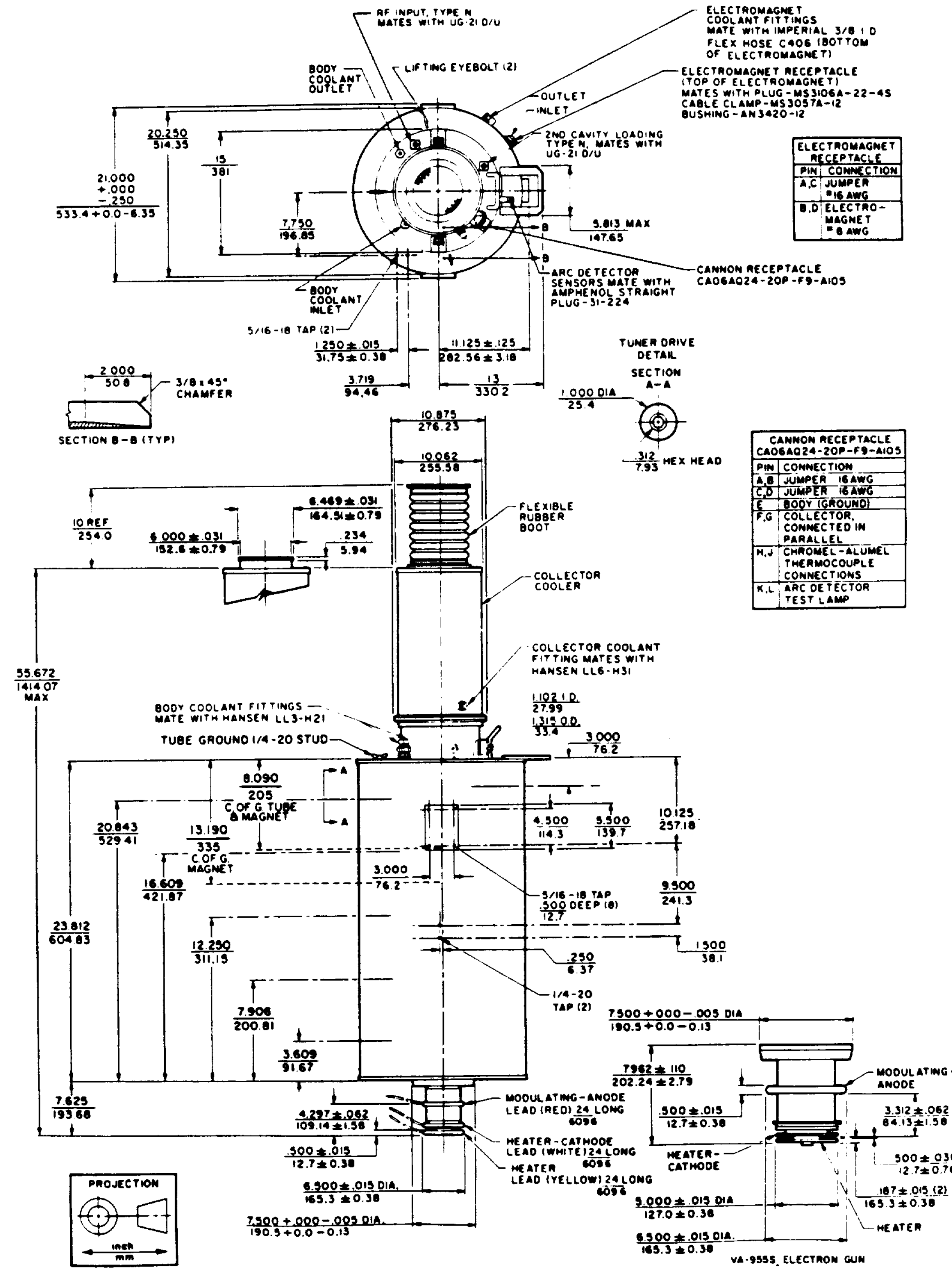
Water Flow, minimum	
Tube Body	2.5 gal/min (0.15 l/s)
Tube Collector	2.0 gal/min (0.12 l/s)
Electromagnet	2.0 gal/min (0.12 l/s)

Pressure Drop, at minimum flow, maximum	
Tube	50 lbf/in² (3.5 kgf/cm²)
Electromagnet	35 lbf/in² (2.5 kgf/cm²)

NOTES:

1. Characteristics and operating values are based on performance tests. These figures may change without notice as a result of additional data or product refinement. Varian should be consulted before using this information for equipment design.
2. For optimum performance, the water inlet temperature should be kept within 5 °C of the coolest practical value.
3. The collector temperature should be monitored using the thermocouple attached to each tube.
4. Ratings should not be exceeded under continuous or transient conditions. A single rating may be the limitation and simultaneous operation at more than one rating may not be possible. Equipment design should limit voltage and environmental variations so that the ratings will never be exceeded.
5. Performance guaranteed only with VCP-7858 variable visual couper.
6. The VKP-7555S has the capability of being tuned as an "H" utilizing current lower power drivers and fixed output coupler. It can be retuned for "S" operation when higher drive power is provided.

OUTLINE DRAWING
VKP-7555S Tube in VA-1952H or VA-1955H Electromagnet



ELECTROMAGNET RECEPTACLE	
PIN	CONNECTION
A,C	JUMPER #16 AWG
B,D	ELECTRO-MAGNET #6 AWG

CANNON RECEPTACLE CA06AQ24-20P-F9-A105	
PIN	CONNECTION
A,B	JUMPER 16 AWG
C,D	JUMPER 16 AWG
E	BODY (GROUND)
F,G	COLLECTOR, CONNECTED IN PARALLEL
H,J	CHROMEL-ALUMEL THERMOCOUPLE CONNECTIONS
K,L	ARC DETECTOR TEST LAMP

OPERATING HAZARDS

Read the following and take all necessary precautions to protect personnel. Safe operating conditions are the responsibility of the equipment designer and the user.

High Voltage. This tube operates at voltages which can be deadly. Equipment must be designed so personnel cannot come in contact with operating voltages. Enclose high-voltage circuits and terminals and provide fail-safe interlocking switch circuits to open the primary circuits of the power supply and to discharge high-voltage capacitors whenever access is required.

Microwave Radiation. Exposure of the human body to microwave radiation in excess of 1 milliwatt per square centimeter is unsafe and can result in blindness or other injury. Personnel must be fully protected from the microwave energy which radiates from this device. All input and output r-f connections, waveguide flanges, and gaskets must be r-f leakproof and properly engaged. Never operate this device without a microwave-energy-absorbing load attached. Personnel must be prevented from looking into open waveguides or antennas while such a device is energized. (Ref. Proc. IRE, Vol. 49, No. 2, pp. 427-447, Feb. 1961).

X-Rays. This device may produce X-ray radiation when energized. Operating personnel must be protected by appropriate shielding. Provide adequate X-ray shielding on all sides of this device, as well as the modulator and pulse transformer tanks. X-ray caution signs or labels must be permanently attached to equipment directing operating personnel never to operate this device without X-ray shielding in place.

Equipment must be designed to fully safeguard all personnel from these hazards. Labels and caution notices must be provided on equipment and in manuals clearly warning of those hazards which cannot be avoided.

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APPENDIX B
VKP-7990 PRELIMINARY TECHNICAL DATA

VKP-7990

MULTISTAGE DEPRESSED COLLECTOR KLYSTRON AMPLIFIER 470-810 MHz

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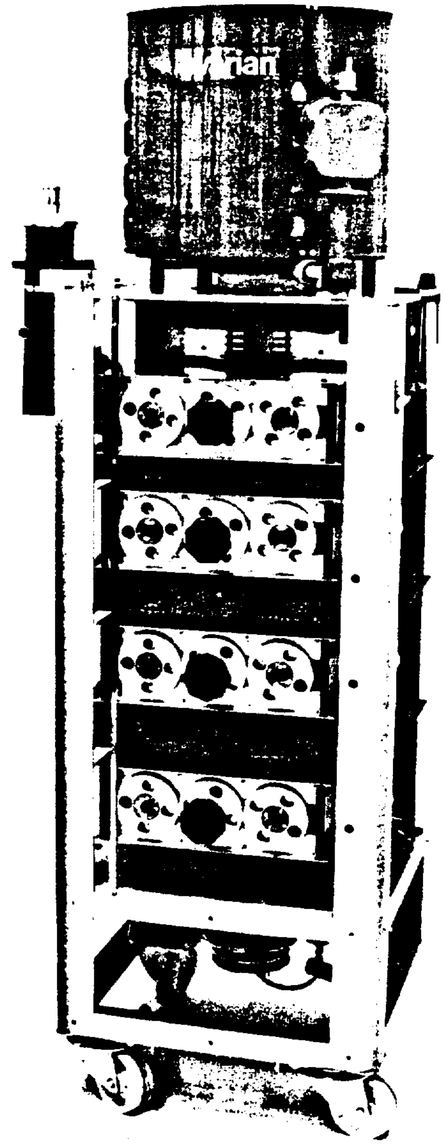
PRELIMINARY TECHNICAL DATA



DESCRIPTION

The VKP-7990 is an external, four-cavity, liquid- and air-cooled klystron, especially designed for UHF-TV transmission. Fitted with appropriate cavity boxes, a single tube covers the entire UHF-TV frequency range, 470 to 810 MHz. The design features a multistage depressed collector (MSDC), providing the means for attaining very high operating efficiency. The VKP-7990 operates in standard "collector-up" external cavity magnet assemblies. Cooling is provided by liquid for the collector and air for the cavities, body, and the magnet assembly.

FEATURES

High Efficiency — Use of the multistage depressed collector provides for collection of various electron groups leaving the rf structure at their exit velocities. This leads to a much lower spent-beam power loss for the same output ratings and the achievement saturated efficiency on the order of 75%. With the implementation of beam pulsing techniques, the Figure of Merit (FOM), which is the ratio of peak-of-sync output power to average dc input power, can reach 130 or more.

Ample Bandwidth — 1 dB bandwidth of at least 6 MHz is readily attained and varies no more than ± 1 dB over the full black to white amplitude range and from -1 MHz to +5 MHz from carrier.

Modulating Anode — Provides the means for optimally adjusting visual beam current and for aural service when a common beam power supply is used. In visual service, conventional mod-anode pulsing can be applied for additional power savings.

Anode Control Electrode (ACE) — Low voltage beam pulsing using the ACE electrode is easily accomplished by holding the mod-anode at a constant voltage, applying fixed bias to the ACE during the video interval and pulsing to cathode potential for each sync interval. Pulse voltages of only a few hundred volts are required for ACE pulsing compared with thousands of volts necessary for mod-anode pulsing. The reduced pulsing voltage allows the use of totally solid-state modulators with their greater reliability. The ACE terminal, located on the cathode assembly, can be easily tied electrically to the cathode for conventional mod-anode control and pulsing.

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GENERAL CHARACTERISTICS[1]

ELECTRICAL

Frequency Range	470 to 810 MHz
Heater Voltage, typ	7.0 Vac
Heater Current, typ	17 Aac
Heater Surge Current, max	30 Aac
Heater Warm-up Time, min	5 min
Focusing	Electromagnet
Electromagnet Voltage, typ	110 Vdc
Electromagnet Current, typ	11 Adc
2nd Cavity Load	200 Watts

PHYSICAL

Dimensions	See Outline Drawing
Weight, approx	
VKP-7990	176 lb/80.2 kg
PTE-5091/5	
Electromagnet	550 lb/250 kg
Mounting Position	Cathode down
Cooling	
Tube	Water and Forced Air
Electromagnet	Forced Air
Water Inlet Temperature,[2] max	70°C

OPERATING CONDITIONS AND RATINGS[1]

	VKP-7990 Typical Operation	Maximum Ratings[3]	
Frequency, visual	519	---	MHz
Output, saturated	64	---	kW
Drive Power, peak-of-sync	20	---	W
Gain, peak-of-sync	35	---	dB
Efficiency, saturated	130	---	% FOM[4]
Bandwidth, 1-dB	6	---	MHz
Beam Voltage	24.5	26	kVdc
Beam Current	5.3	7.0	Adc
Body Current	50	100	mAdc
Modulating Anode Voltage	19.5	26	kVdc
Modulating Anode Current	0.5	5	mAdc
Focusing Current	11	15	Adc
ACE Voltage	See Curves	1400	Vdc
Ion Pump Voltage	3.2	3.5	kVdc
Load VSWR	<1.1:1	1.5:1	

COOLING

Distilled water is the preferred coolant. Water purity should be maintained in accordance with the information contained in the Varian Application Engineering Bulletin AEB-31. In addition, at least 200 lb/h (90.8 kg/h) of clean dry air should be directed at the cathode. For additional information, contact the nearest Varian Sales Office or the Varian Microwave Tube Division, Palo Alto, California.

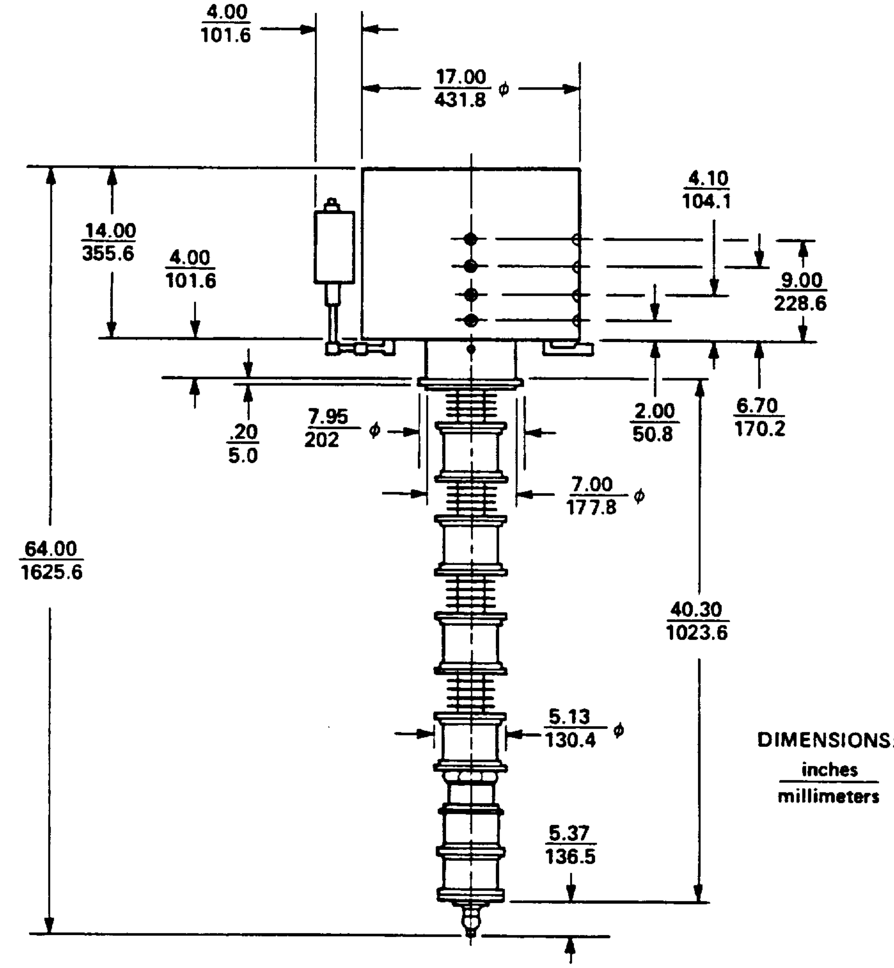
Water flow, minimum
Tube Collector .... 6.0 gal/min

Pressure Drop, at minimum flow, maximum
Tube .... 31 lbf/in^2

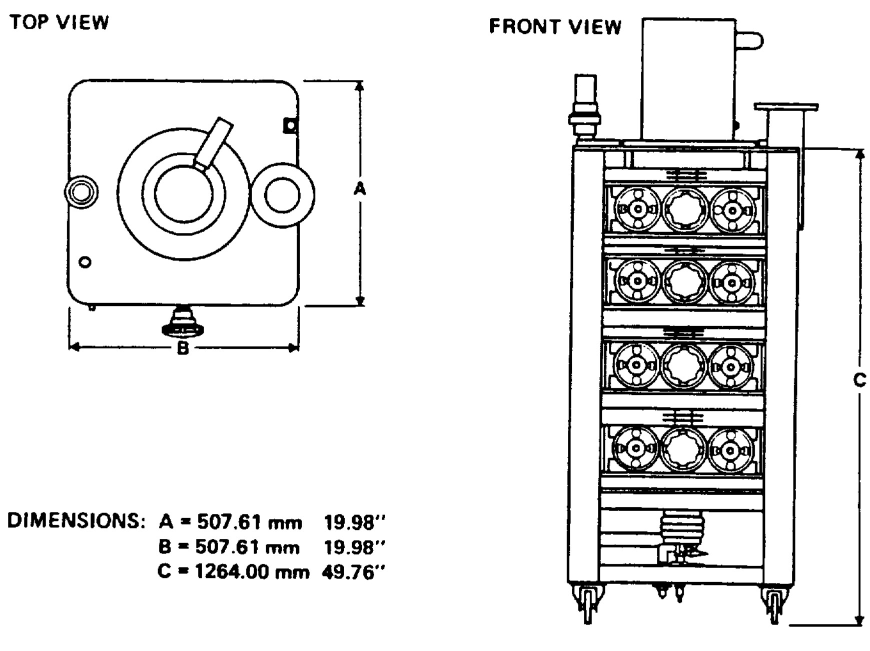
NOTES:

1. Characteristics and operating values are based on performance tests. These figures may change without notice as a result of additional data or product refinement. Varian should be consulted before using this information for equipment design.
2. For optimum performance, the water inlet temperature should be kept within 5°C of the coolest practical value.
3. Ratings should not be exceeded under continuous or transient conditions. A single rating may be the limitation and simultaneous operation at more than one rating may not be possible. Equipment design should limit voltage and environmental variations so that the ratings will never be exceeded.
4. FOM = Figure of Merit: The quotient of peak-of-sync output power and the average dc beam input power.

OUTLINE DRAWING
VKP-7990

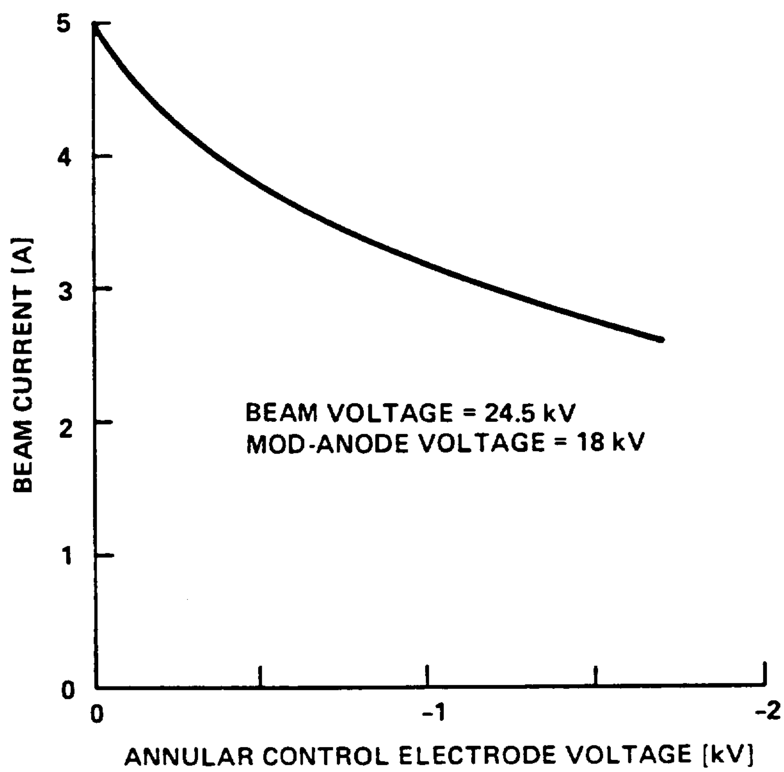


OUTLINE DRAWING — PTE5091/5



DIMENSIONS: A = 507.61 mm 19.98"
B = 507.61 mm 19.98"
C = 1264.00 mm 49.76"

CHARACTERISTIC CURVE



OPERATING HAZARDS

Proper use and safe operating practices with respect to microwave tubes are the responsibility of equipment manufacturers and users of such tubes. Varian provides information on its products and associated hazards, but it assumes no responsibility for after-sale operating and safety practices. Limited life and random failures are inherent characteristics of electron tubes. Take appropriate action through redundancy or safeguards to protect personnel and property from tube failure.

All persons who work with or are exposed to microwave tubes or equipment which utilizes such tubes must take precautions to protect themselves against possible serious bodily injury. Do not be careless around such products.

WARNING — SERIOUS HAZARDS EXIST IN THE OPERATION OF MICROWAVE TUBES

The operation of microwave tubes involves one or more of the following hazards, any one of which, in the absence of safe operating practices and precautions, could result in serious harm to personnel:

a. HIGH VOLTAGE — Normal operating voltages can be deadly.

b. RF RADIATION — Exposure to rf radiation may cause serious bodily injury possibly resulting in blindness or death. *Cardiac pacemakers may be affected.*

c. X-RAY RADIATION — High voltage tubes produce dangerous, possibly fatal, x-rays.

d. BERYLLIUM OXIDE POISONING — The dust or fumes from beryllium oxide (BeO_2) ceramics used in microwave tubes are highly toxic and can cause serious injury or death.

e. CORROSIVE AND POISONOUS COMPOUNDS — Upon microwave or high voltage breakdown in the external waveguide portion of microwave tubes, a dielectric gas which is sometimes used may combine with impurities to form highly toxic and corrosive compounds.

f. IMPLOSION HAZARD — Ceramic windows in microwave tubes can shatter on impact or crack in use, possibly resulting in injury from flying particles or from beryllium oxide (BeO_2) dust or fumes.

g. HOT WATER — The electron collector and water used to cool it reach scalding temperatures. Touching or rupture of the cooling system can cause serious burns.

h. HOT SURFACES — Surfaces of air-cooled collectors and other parts of tubes can reach temperatures of several hundred degrees centigrade and cause serious burns if touched.

Please see the Microwave Tube Division Operating Hazard Sheet (Publication No. 3386) for more details on operating hazards.

References

1. H.G. Kosmahl, "Multistage Depressed Collectors (MDC) for Efficiency Improvements of the UHF Broadcast Klysytrons", IEEE Broadcasting Symposium, Washington, D.C., September 1982.

2. R.S. Symons, "Depressed Collector Klystrons for High Efficiency UHF Television", NAB Convention, Dallas, April 1981.

3. C.C. Culter, "New Opportunities for UHF Television Transmitters", UHF Comparability Task Force, Office of Plans and Policy, Federal Communications Commission, Washington, D.C., February 1981.

4. H.G. Kosmahl, "Modern Multistage Depressed Collectors — A Review", Proceedings of the IEEE, November 1982.

5. E.G. Wintucky, A.N. Current, J.S. Sovey, "Electron Reflection and Secondary Emission Characteristics of Sputter-Textured Pyrolytic Graphite Surfaces", NASA Technical Memorandum 81755, April 1985.

6. A.N. Curren, K.A. Jensen, "Textured Carbon on Copper: A Novel Surface with Extremely Low Secondary Electron Emission Characteristics", NASA TP 2543, December 1985.

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16. Abstract

This report describes a program to incorporate depressed collector technology into UHF-TV klystron power amplifiers. The program objective was to develop a klystron with enhanced efficiency where power consumption would be reduced to half in TV service. A design was achieved using computer-aided design technology. Also developed were carbon coating techniques to minimize the adverse effects of secondary electrons. An experimental 60 kW klystron was constructed and evaluated. The collector design uses four stages operating at equally spaced depressed potentials. Current distribution to the collector electrodes was measured and power recovery determined. The magnitude of regeneration was also determined and the effectiveness of secondary electron suppression noted. The performance results indicate 74% power recovery with no rf output reducing to 57% at saturation, representing an overall efficiency of 71%. Regeneration was low enough to allow stable operation with up to 60 dB gain.

17. Key Words (Suggested by Author(s))	Klystron Amplifiers Multistage Depressed Collectors UHF Television Transmitters
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